

Paths to the Knot

This is part of the MAZE-project.

A Reference Work: How Every Human Science Arrives at the Same Object From Its Own Accepted Ground

Complete edition — Parts One, Two and Three in a single volume

J. Konstapel Leiden, 17 August 2026.: **Email:** hans.konstapel@gmail.com.

0. Introduction

0.1 The same discovery, made forty times

In 1977, three linguists studying ordinary telephone conversation published a paper on the organisation of *repair*. They had found that talk is shot through with trouble — mishearings, false starts, wrong words — and that participants correct it continuously, by a system so regular it could be written down. Their conclusion was that conversation is not held together by the absence of trouble but by the machinery that fixes it.

In 1974, a computer scientist defined *self-stabilization*: a distributed system that, from any arbitrary state, converges to a correct one and stays there, without outside intervention. He proved it for concrete algorithms. It became the foundation of how large systems are built, because nothing else works at scale.

In 1990, two political theorists writing on care defined it as everything we do to *maintain, continue and repair* our world so that we can live in it as well as possible.

In 2008, four biologists proposed *proteostasis* as a therapeutic target: the network of synthesis, folding, chaperoning and degradation that keeps a cell's proteins in the state they are supposed to be in. On their account the disease is a failure of maintenance rather than of a component.

In 1989, a sociologist studying the American women's movement between the suffrage victory and the nineteen-sixties described *abeyance structures*: small networks that keep a movement's repertoire, personnel and identity alive through decades when mobilisation is impossible.

In 2000, an anthropologist collected work on *relatedness* — kinship as something continually made by feeding, sharing, naming and co-presence, which lapses when the acts stop.

In 1960, a classicist showed that a Balkan singer performing an epic of thousands of lines does not recite a text. He recomposes it at each performance, in different words every time, and it is the same song.

Seven fields. Seven vocabularies. One object.

This book documents forty more. The full list of names includes turnover, routine, entrainment, soft assembly, calibration, traceability, adstock, currency, going concern, susceptible replenishment, error threshold, structural inertia, renewal, refreshing, scrubbing, and preventive conservation.

None of these literatures cites the others. A conversation analyst has no reason to read a paper on distributed consensus. A conservator does not follow molecular genetics. And so a discovery made independently in dozens of disciplines has never been recognised as one discovery.

0.2. Why nobody noticed

There is a reason this object slipped through, and it is structural rather than accidental.

Maintenance produces no change. Its entire output is that something is still there. And nearly every measurement system in the sciences of Part One is built to detect difference: before and after, treatment and control, trend and deviation. An activity whose success is indistinguishable from nothing having happened is invisible to instruments calibrated on change.

This is why care work is undervalued, why infrastructure budgets are cut, why audit is described as producing comfort rather than product, and why the maintenance of a discipline's own standards is nobody's research topic. It is the same blind spot each time, and it has a shape.

The disciplines that did see it are the ones where the failure is immediate and expensive. Aviation regulates skill currency because pilots who have not landed recently crash. Distributed systems are built to self-stabilise because at scale something is always broken. Conservators know that nothing is preserved by being left alone. Where neglect is punished quickly, the object becomes visible.

0.3. The object

A knot is a pattern of connections that persists because it is continually re-laid.

Not because it is stored somewhere. Not because it is made of durable parts. Not because it is left alone. Connections lapse when nothing runs across them; new ones are laid where something does. Whatever is still there is still there because it lays itself again, faster than it falls away.

Two numbers, and only two, distinguish one knot from another.

Form — which connections, in what order, crossing which others. Form is what makes this knot this one and not another. It is the personality, the genome, the constitution, the tune, the text, the culture.

Depth — how many times the thing has been closed. A knot of knots. Each closing takes connections that were open and turns them inward, which leaves the whole less open and therefore slower. Depth is why a molecule turns over in moments, a cell holds longer, a person holds for decades, and an institution longer still. These are not different kinds of thing. They are one construction at different heights.

Both quantities are countable, and both are already studied. Lay the connections of a knot out along a line: two connections either *cross*, when their endpoints alternate, or *nest*, when one lies wholly inside the other. Form is the crossing structure; depth is the nesting structure. These are the two standard statistics of a chord diagram, and Chen, Deng, Du, Stanley and Yan proved their joint distribution symmetric — they stand on equal mathematical footing.

The technical appendix, identical at the end of each part, derives everything quantitative in seven steps from a single continuous line.

0.4. Three consequences that recur everywhere

Three results follow from the appendix, and between them they account for most of what the sixty-five chapters find.

There is an upper bound on form. The largest pattern a knot can hold equals its repair-to-decay ratio — how many times faster it puts connections back than they lapse. How fast it works does not enter; only the ratio does.

This is the model's central inequality, and it is the one place where it has been checked against measurement by an independent route. Eigen established it for replicating molecules in 1971: the product of per-base error rate and genome length must stay below one. RNA viruses sit at the bound. The human genome sits inside the measured range of its own. The same inequality governs how much culture a small population can carry, how many manuscripts a scriptorium can keep alive, and how large an organisation a given administrative capacity can hold.

Rest is required and its size is fixed. Re-laying is imprecise; some of what is laid lands beside the pattern and must be put back; and putting back happens only in phases when nothing is running through. So every knot must spend a fraction of its time not operating, and that fraction is the size of its form divided by its repair-to-decay ratio.

The required fraction contains no term for effort. What determines whether a knot holds is not how hard it works but whether it reaches zero often enough. A knot prevented from reaching zero falls below its requirement however light the load.

Depth is finite, and failure runs from the top down. Each closing multiplies the pattern to be maintained while the bound does not move, so towers are short — a thousandfold increase in repair capacity buys a handful of further levels, not a thousand. And when repair capacity falls, the largest pattern goes first, which is the deepest layer. The state before the guild, the guild before the household. Ageing removes the top of the tower while the lower levels hold.

0.5. Method

Every chapter follows the same six steps, and the first is the important one.

1. **The accepted starting point.** What the field takes for granted before it begins work — the finding no school within it disputes.
2. **Where it stalls.** The question that starting point raises and the field has not closed.
3. **What the field already measures.** Data it has, usually collected for another purpose.
4. **The turn.** What follows if those measurements are taken at face value.
5. **Depth and form here.** The two quantities in that field's own terms.
6. **What follows.** What the field gains that it does not currently have.

A bridge is only a bridge if it starts on the bank where the reader is standing. So no chapter begins with the model and looks for confirmations. Each begins where its discipline begins, walks forward in that discipline's vocabulary using its own measurements, and arrives.

This means the chapters can be read in any order, and read alone. A physician can read Chapter XXXI without reading anything else in the book, and without accepting the model in advance.

0.6. What this book credits

The object was not discovered here.

In most of these fields somebody got there first, in their own domain, often decades ago, and named it well. Conversation analysis named repair. Cell biology named proteostasis. Distributed computing named self-stabilization. Care ethics gave the earliest correct general definition, in 1990, from a concern with unpaid labour. Ingold, in social anthropology, arrived at the whole picture — a world of life woven from knots rather than built from blocks — from ethnography, and wrote it out in 2015.

What this book adds is that these are one object, that the object has two numbers, and that the numbers behave the same way at every depth.

0.7. Contents

Part One — The Social and Human Sciences. I Sociology · II Social Network Analysis · III Social and Cultural Anthropology · IV Kinship Studies · V Linguistics · VI Conversation Analysis and Ethnomethodology · VII Folklore and Oral Tradition · VIII Personality Psychology · IX Developmental Psychology · X Clinical Psychology and Psychotherapy · XI Social Psychology of Close Relationships · XII Economics · XIII Institutional Economics and Political Economy · XIV Organisation Studies · XV Political Science and State Formation · XVI Law · XVII Archaeology · XVIII Demography · XIX Urban Studies and Infrastructure · XX History and Cultural Memory · XXI Ritual Studies · XXII Ethnomusicology and Entrainment · XXIII Education and the Science of Learning · XXIV Archives, Preservation and Digital Curation.

Part Two — The Life Sciences, Medicine, and the Formal Sciences. XXV Biochemistry and Proteostasis · XXVI Molecular Genetics and the Error Threshold · XXVII Cell Biology · XXVIII Immunology · XXIX Microbiome Research and Holobiont Biology · XXX Neuroscience · XXXI Medicine · XXXII Gerontology · XXXIII Epidemiology · XXXIV Psychiatry · XXXV Rehabilitation and Exercise Physiology · XXXVI Ecology · XXXVII Evolutionary Biology · XXXVIII Developmental Biology and Regeneration · XXXIX Mathematics: Chord Diagrams and Knot Theory · XL Physics · XLI Distributed Systems and Computer Science · XLII Cybernetics and Systems Theory · XLIII Information Theory.

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0.8. How to use it

Read your own chapter first. It will begin with something you already accept and it will not ask you to take anything on trust before step four.

Then read one chapter from a field you know nothing about, and notice that it contains the same argument. That is the actual demonstration, and it cannot be made in the abstract.

The technical appendix is at the end of each part. Anyone who wants to check a number will find it derived there in seven steps.

And there is a practical suggestion running through the book, which recurs so often that it belongs in the introduction. In field after field, both rates exist in the literature — the rate at which something lapses and the rate at which it is put back — measured by different specialists for different purposes, and never divided by one another. Skill decay and retraining. Relational decay and restoration. Deconditioning and recovery. Deterioration and conservation. That division is usually a day's work with existing data, and it produces the one number on which everything else here depends.

0.9 Annotated References — Introduction

Schegloff, E., Jefferson, G. & Sacks, H. (1977). The preference for self-correction in the organization of repair in conversation. *Language* 53(2), 361–382. *Why read? The field that named repair and showed that interaction runs on it. The clearest short statement in the human sciences that a thing is held together by its correction machinery.*

Dijkstra, E.W. (1974). Self-stabilizing systems in spite of distributed control. *Communications of the ACM* 17(11), 643–644. *Why read? Two pages. Convergence to a correct state from any state, without outside intervention, proved. The same object built deliberately, because at scale nothing else works.*

Fisher, B. & Tronto, J. (1990). Toward a Feminist Theory of Caring. In E. Abel & M. Nelson (eds.), *Circles of Care*. SUNY Press. *Why read? Care defined as everything we do to maintain, continue and repair our world. The earliest correct general definition of the object, written from a concern with unpaid labour.*

Balch, W.E., Morimoto, R.I., Dillin, A. & Kelly, J.W. (2008). Adapting proteostasis for disease intervention. *Science* 319(5865), 916–919. *Why read? Maintenance as a therapeutic target — disease as a failure to keep re-laying rather than a broken component.*

Taylor, V. (1989). Social Movement Continuity: The Women's Movement in Abeyance. *American Sociological Review* 54(5), 761–775. *Why read? Continuity through decades of impossibility, achieved by a reduced structure doing continuous maintenance. The general behaviour of any knot under falling capacity, caught in one case.*

Carsten, J. (ed.) (2000). *Cultures of Relatedness*. Cambridge University Press. *Why read? Kinship as continually made and fed, and lapsing when the feeding stops. Read the introduction.*

Lord, A.B. (1960). *The Singer of Tales*. Harvard University Press. *Why read? The cleanest documented case anywhere: a poem of thousands of lines re-laid in new words at every performance and remaining the same poem, recorded in the field with comparative recordings.*

Ingold, T. (2015). *The Life of Lines*. Routledge. *Why read? Part One is titled Knotting. A world of life woven from knots rather than built from blocks, argued from ethnography. The closest existing statement of the whole object in any discipline, missing only the counting.*

Eigen, M. (1971). Selforganization of matter and the evolution of biological macromolecules. *Naturwissenschaften* 58(10), 465–523. *Why read? The error threshold: the largest maintainable*

pattern set by the ratio of correction to corruption. The one place where this book's central inequality has been established independently, with numbers.

Shannon, C.E. (1948). A mathematical theory of communication. *Bell System Technical Journal* 27, 379–423 and 623–656. *Why read? Reliable retention over an unreliable medium, bounded by the same ratio, proved in general form. Information theory did not set out to characterise living things and produced the bound that governs them.*

Chen, W.Y.C., Deng, E.Y.P., Du, R.R.X., Stanley, R.P. & Yan, C.H. (2007). Crossings and nestings of matchings and partitions. *Transactions of the American Mathematical Society* 359(4), 1555–1575. *Why read? The two statistics of a chord diagram and their symmetric joint distribution — form and depth on equal mathematical footing. The proof runs through tableaux and can be skipped; the statement is the point.*

Konstapel, J. & Claude (2026). *The Human as Knot*. constable.blog. *Why read? The derivation of form and depth from a single continuous line, and the account of what a person is once the two numbers are in place. This book applies that derivation without repeating it.*

Konstapel, J. (2026). *The Vacuum.Net Theory: Foundational Paper*. constable.blog. *Why read? For the origin of the picture — one line, contacts, flow. No chapter in this book depends on it.*

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Technical Appendix: From One Line to Two Numbers

How this book is built

A bridge is only a bridge if it starts on the bank where the reader is standing.

This work therefore does not begin with a model and look for confirmations. It begins, in each chapter, with what a discipline already accepts without argument — the finding no school within it disputes. From there it walks forward in that discipline's own vocabulary, using its own measurements, until one object appears.

That object is the knot.

Each chapter has the same six steps.

1. The accepted starting point. What the field takes for granted before it begins work.
2. Where it stalls. The question that starting point raises and the field has not closed.
3. What the field already measures. The data it has, usually collected for another purpose.
4. The turn. What follows if those measurements are taken at face value.
5. Depth and form here. The two quantities, in that field's terms.
6. What follows. What the field gains that it does not currently have.

The object, stated once

A knot is a pattern of connections that persists because it is continually re-laid.

Not because it is stored, not because it is built out of durable parts, and not because it is left alone. Connections lapse when nothing runs across them. New ones are laid where something does. Whatever is still there is still there because it lays itself again, faster than it falls away.

Two numbers, and only two, distinguish one knot from another.

Form — which connections, in what order, crossing which others. Form is what makes this knot this one and not another.

Depth — how many times the thing has been closed. A knot of knots. Each closing takes boundary inward, which makes the whole slower and longer-lasting than its parts.

Both are countable. Form is the crossing structure of the pattern; depth is its nesting structure. In the combinatorics of chord diagrams these are the two standard statistics, and Chen, Deng, Du, Stanley and Yan proved that their joint distribution is symmetric. They stand on equal mathematical footing.

There is one further consequence, and it recurs in nearly every chapter below. Re-laying is not exact. Some of what is laid lands beside the pattern rather than in it, and has to be put back. Putting back happens only in phases when nothing is running through. So every knot must spend a fraction of its time not operating, and that fraction rises with the size of the pattern it maintains.

What this is not

It is not a claim that these disciplines are wrong. Every chapter begins from a finding the field established, and most of them established it long before this model existed.

It is not a claim of priority. In several fields the word for this object is already in use — repair in conversation analysis, proteostasis in cell biology, self-stabilization in distributed computing, maintenance in infrastructure studies. Those fields got there first, in their own domain.

What is new is that they are all describing one object, that the object has two numbers, and that the numbers behave the same way at every depth.

A note on this edition

The three parts were written and circulated separately. They are here in one volume, in the order in which they were written, with the chapter numbering running unbroken from I to LXV.

Three things have been done and nothing else. The technical appendix, which stood identically at the end of each part, now stands once at the end of the book, with its chapter references merged. The three reference lists have been merged into one, with the entries that appeared in more than one part given once. The introductory restatement of the object at the head of Parts Two and Three has been cut, since the statement stands at the head of the book.

Part One — The Social and Human Sciences

I. Sociology

The accepted starting point. An organisation remains the same organisation while its entire staff is replaced. A family persists across generations. A university founded in 1575 still exists and not one of its founders does. No school of sociology disputes this.

Where it stalls. The field has words for what persists — structure, institution, culture, role, norm — and none of them says what the persisting thing is. Structure is defined as the pattern in the relations, which moves the question rather than answering it: which pattern, and residing where?

The unresolved dispute runs from Durkheim and Weber to the present. Does a collective exist in its own right, or is it a convenient way of speaking about many individuals? Sociology did not settle this. It divided into camps and carried on.

What the field already measures. Giddens came closest to an answer and stopped one step short. In structuration theory, structure has no existence outside its instantiation in practice; it is recursively organised and exists only as it is reproduced. Archer's morphogenetic approach makes the same move over time. Emirbayer's relational manifesto argues that the relation, not the entity, is the unit.

And there is data. Ties decay measurably without contact, and recover on renewed contact — Roberts and Dunbar recorded time to last contact against reported closeness across personal networks.

The turn. If structure exists only as it is reproduced, and if ties lapse without contact, then the durable thing is not the tie and not the structure as observed at a moment. It is the pattern in which ties are laid again.

That pattern is the knot. Giddens' recursively reproduced structure is a knot without a count.

Depth and form here. Form is which relations must be maintained and in what arrangement: what makes this firm this firm. Depth is how many times closure has been repeated — person, team, department, firm, sector. Each closing lengthens the retention time of the whole.

What follows. The old dispute gains a criterion instead of a position. A collective exists when its joint repair gets round its joint pattern, and does not when it fails to. Both camps were right about different cases.

Maintenance machinery — assembly, ritual, archive, correspondence, administration — stops being overhead that accretes on organisations and becomes the means by which repair is kept large enough for the pattern. Remove it while keeping the size, and the knot loosens.

And growth is discontinuous. One more member costs and returns nothing. Return arrives only when a further layer closes.

II. Social Network Analysis

The accepted starting point. Social structure can be represented as nodes and edges, and the representation supports prediction. Density, centrality, clustering and brokerage are measured routinely and travel across substantive domains.

Where it stalls. The node is an assumption. Ask what a node is made of and there is no answer inside the field; the node is where measurement begins. Ask what the graph is a part of and there is no answer either; the graph is where measurement ends.

So the field has a floor and a ceiling it cannot look past, and both are artefacts of the instrument.

What the field already measures. Temporal network analysis discovered the relevant fact from inside. Holme and Saramäki's synthesis showed that when edges are treated as events with timing rather than as standing links, results change: paths become time-respecting, and connectivity that looks robust in the aggregated graph turns out to be intermittent. Snijders' actor-oriented models fit tie formation and dissolution as ongoing processes rather than a state.

Granovetter's weak ties, on inspection, are weak precisely because they are re-laid rarely.

The turn. A social graph is not a structure that stands. It is a structure that is continually re-laid, and any snapshot is a sample of an ongoing process. What persists across snapshots is the pattern of re-laying.

Depth and form here. Form is the graph as the field already draws it: which edges, which arrangement. Depth is what the field does not have. A node is a knot one layer down; the whole graph is a node one layer up. Network analysis flattens the ladder onto a single plane by construction.

What follows. Depth supplies the missing dimension without abandoning any existing method. Multilayer network analysis already reaches for it and gets partway, treating layers as parallel relation types rather than as nested closures.

And it supplies a threshold. A cluster in a graph is not automatically a thing. It is a thing when its joint repair gets round its joint pattern. Community detection currently returns communities whether or not anything closed.

III. Social and Cultural Anthropology

The accepted starting point. Societies persist while their members are replaced entirely, and they persist without written constitutions, central authority, or storage. Ethnography has documented this everywhere it has looked.

Where it stalls. Structural-functionalism explained persistence by structure and was abandoned for good reasons: it could not account for change and it reified what it described. What replaced it — practice theory, then the ontological turn — gained change and lost the account of persistence.

What the field already measures. Ingold has said the thing outright. In *The Life of Lines* he argues that a world of life is woven from knots rather than built from blocks, that every living being is a line or a bundle of lines, and that a meshwork differs from a network in having knots where lines are drawn together rather than nodes joined by connectors. What such lives do with one another he calls correspondence.

Strathern's dividual and Wagner's fractal person make the parallel move on the individual: the person is composed of relations rather than being a unit that enters into them. Latour's Actor-

Network Theory insists that a group exists only while it is being performed, and that groups must be continually re-formed or they cease.

The turn. These are the same statement from three directions. Ingold has the picture, Strathern has the person, Latour has the performance. What none of them has is number.

Depth and form here. Form is the specific pattern of relations that makes this group this one — Strathern's point, made precise. Depth is what Latour's flat ontology explicitly refuses, and it is the price of that refusal: ANT cannot say that a person is a knot at one depth and an institution a knot at another, so it must treat both as actors in the same plane.

What follows. Persistence and change stop being rival explanations. Persistence is re-laying into the same class; change is re-laying into another. Both are the same operation, and which one is happening is a question about the class, not about the ethnographer's theoretical commitments.

IV. Kinship Studies

The accepted starting point. Kinship is not read off biology. Schneider's critique established that the genealogical grid is an analyst's construct rather than a native category, and the field has not gone back.

Where it stalls. If kinship is not biological descent, what is it? The field's answer, since Carsten, is relatedness: kinship as something made rather than given. That is correct and it is not yet a definition. Made how, and what makes it stop?

What the field already measures. This is the field's own strongest finding, and it is unusually direct. Relatedness has to be fed. It is produced and maintained by sharing food, sharing a house, feeding, naming, co-presence and repeated acts of care. Carsten's Malay material shows kinship

being made through shared substance and shared hearths over time. The adoption literature describes kinning as a process rather than an event.

And relatedness lapses. A kin tie unfed becomes nominal, then nothing. Every ethnographer knows this and it is rarely stated as a finding.

The turn. Kinship is a pattern of connections maintained by repeated acts, which lapses when the acts stop. That is a knot, stated without alteration.

The field arrived here before the model did. What it lacks is the two numbers.

Depth and form here. Form is which relations are fed and how — the specific pattern that makes this a household and that a lineage. Depth is the nesting the field already draws and does not treat as a quantity: person, household, lineage, clan, moiety. Each is a closure over the one below.

What follows. The old opposition between descent theory and alliance theory becomes a question about depth. Descent describes closure along one axis, alliance the laying of ties that close a further layer over two existing knots.

And the model supplies what "relatedness" has lacked since 2000: a stopping condition. A kin group exists while the feeding gets round the pattern.

V. Linguistics

The accepted starting point. A language persists while every one of its speakers is replaced. No speaker holds the whole of it, and there is no copy anywhere.

Where it stalls. Saussure's langue is the classical answer: a system existing in the collectivity, separate from parole. It has never been located. Chomsky relocated it inside the individual as competence, which solves the storage problem for one head and reopens it for the community.

What the field already measures. Usage-based linguistics measured what happens when forms are not used. Bybee's work on frequency shows that entrenchment depends on repetition, that high-frequency forms resist regularisation while low-frequency forms are swept into regular patterns, and that grammatical structure emerges from and is maintained by use. Hopper's emergent grammar states the conclusion: grammar is not a prior structure that speech instantiates but a running deposit of speech.

Historical linguistics measures the decay side. Forms not re-laid are regularised or lost, and the rate depends on frequency.

The turn. A language is not stored anywhere and is not a thing speakers instantiate. It is a pattern of connections that persists because a population keeps laying it again, and the parts that stop being laid disappear on a schedule set by how often they were laid.

Depth and form here. Form is the specific pattern — this language and not that one. Depth is the nesting the field already treats as levels: phoneme, morpheme, word, construction, discourse. Each is closed over the one below, and each has its own rate of change. The observation that phonology changes faster than syntax is an observation about depth.

What follows. Language death gains a mechanism that is not sociological in the loose sense. A language stops when the re-laying no longer gets round the pattern — when the number of

maintained forms exceeds what the remaining speakers can lay per unit time. That is a computable threshold rather than a description after the fact.

VI. Conversation Analysis and Ethnomethodology

The accepted starting point. Conversation is orderly, and its order is produced locally, turn by turn, by the participants. Sacks, Schegloff and Jefferson demonstrated that turn-taking is managed by a small set of rules operating at transition-relevance places, and the finding has held for fifty years across languages.

Where it stalls. If order is produced locally and not imposed, what carries it between occasions? Ethnomethodology's answer is that it is produced afresh each time, which is correct and leaves the recurrence unexplained.

What the field already measures. This field named the mechanism before anyone else, and used the word.

Repair is a technical term in conversation analysis. Schegloff, Jefferson and Sacks described the organisation of repair in conversation and showed it is pervasive, systematically ordered, and strongly biased toward self-repair in the same or next turn. Trouble is continuous; the machinery for fixing it runs continuously; and the conversation is held together by that machinery rather than by the absence of trouble.

The turn. An interaction is a pattern of connections held together by continuous repair. The field established this empirically and calls it by its name.

What it did not do is generalise. Conversation analysis treats repair as a property of talk. It is a property of anything that persists.

Depth and form here. Form is the sequence structure: which actions in which order, adjacency pairs and their expansions. Depth is the nesting the field already transcribes without counting — sound, turn constructional unit, turn, sequence, topic, encounter, relationship. Insertion sequences are literally nested chords.

What follows. The preference for self-repair over other-repair stops being a social nicety and becomes a structural fact: repair from within the closure is cheaper and does not disturb the boundary. Other-initiated repair crosses a boundary and is therefore marked and delayed, which is exactly what the data show.

And the field's central puzzle — what carries order between occasions — is answered without adding a store. Nothing carries it. It is laid again, and what is laid again is the class.

VII. Folklore and Oral Tradition

The accepted starting point. Epic poetry of great length was composed and transmitted for centuries without writing. Parry and Lord established, from fieldwork with living South Slavic singers, that this is possible because the singer does not memorise a text.

Where it stalls. If there is no text, what is the poem? The field's answer is that the poem exists in performance. That is right, and it leaves the identity of the poem unspecified. Two performances differ in every line and are the same song.

What the field already measures. Lord documented this directly. The singer recomposes at each performance from formulas and themes, at speed, under the constraints of metre. Line-by-line comparison of the same song by the same singer on different occasions shows substantial variation and stable identity. The singer insists he sang it the same way, and by his criterion he did.

The turn. The song is not a text and not a memory. It is a pattern that is re-laid at each performance, in different material each time, recognisably the same.

This is the cleanest instance of the object anywhere in the human sciences, and it was documented in the nineteen-thirties.

Depth and form here. Form is the pattern that must return for this to be that song: sequence of themes, the shape of the story, the crossings that make it this one. Depth is the nesting the field already names — formula, line, theme, song, cycle.

What follows. The long argument over whether the Homeric poems are the work of one poet or a tradition dissolves. Both, at different depths. A cycle is a knot over songs; a song is a knot over themes; and the identity of each lives at its own level.

And writing gains a precise description. Writing does not preserve the song. It replaces re-laying with storage, which is a different mechanism with different failure modes — and it is why traditions collapse rather than fade when literacy arrives.

VIII. Personality Psychology

The accepted starting point. Individual differences are stable over long intervals. Rank-order consistency of traits increases with age and remains substantial across decades, as Roberts and DelVecchio's meta-analysis established.

Where it stalls. What is stable? The trait is a summary of behaviour across situations, not a thing found in a person. The field is candid that traits are descriptive. Nothing in the substrate is stable: synapses, proteins, cells and circumstances all turn over.

What the field already measures. Two findings sit uneasily together. Rank-order stability is high, and mean-level change is real and lifelong. Longitudinal work also shows something the field notes and rarely theorises: change is not smooth. Long stretches of stability are punctuated by periods of reorganisation, often around transitions.

The turn. If the substrate is fully replaced and the description stays constant, the constant thing is a pattern that is being laid again — not a store, not a residue, not a set of parameters located anywhere.

Depth and form here. Form is the personality, precisely: which connections, in what arrangement. It is not a point in a five-dimensional space; the five dimensions are a projection of the pattern onto axes chosen for their statistical convenience.

Depth is the ladder the field crosses constantly without a term for it: state, mood, habit, trait, identity. These differ in how long they hold, and they differ in that way because they sit at different depths.

What follows. Identity change becomes discrete rather than gradual. A pattern belongs to a class or it does not; there is no half-membership. Drift accumulates within the class and then gives way at

once. That is a prediction about intensive longitudinal data, and it contradicts the continuous-trajectory models currently fitted to it.

IX. Developmental Psychology

The accepted starting point. Development produces stable outcomes from unstable material. Children with wholly different experiences arrive at similar competences, and the same child's nervous system is unrecognisable from year to year.

Where it stalls. The classical answer is a programme: something specifies the outcome and the organism executes it. The field has moved away from this and has not fully replaced it.

What the field already measures. Thelen and Smith's dynamic systems account showed, from the study of infant reaching and walking, that stable behaviours are softly assembled from components in the moment rather than retrieved from a stored plan. Remove a component and the behaviour reorganises. Change the conditions and a stable pattern dissolves and reforms.

The A-not-B error, treated as a stage marker for decades, turned out to be an assembly effect that can be produced and removed by manipulating the task.

The turn. A developmental achievement is not stored and not executed. It is a pattern that assembles and holds while the conditions for laying it are present.

Thelen and Smith called this soft assembly. It is the same object.

Depth and form here. Depth is what dynamic systems theory conspicuously lacks and needs. Its attractors are on one landscape. What development does is close: components become one component, and the resulting whole becomes a component of something slower. That is why development has stages at all — stages are depths.

Form is what makes this child's competence this one rather than the species-typical average.

What follows. Critical periods stop being windows in a timetable. A layer can close only over constituents that are themselves holding. If the layer below has not stabilised, the closure above has nothing to close over, and by the time it has, the conditions have moved. That is a structural account of timing rather than a stipulated schedule.

X. Clinical Psychology and Psychotherapy

The accepted starting point. The therapeutic alliance predicts outcome across modalities, and it does so more reliably than technique. This is among the most replicated findings in the field.

Where it stalls. Why an alliance should do this is not settled. It is not a technique, not a content, and not a trait of either party.

What the field already measures. This field, like conversation analysis, arrived at the word by itself. Safran and Muran's work on rupture and repair showed that alliances are not steadily good; they rupture routinely, and outcome depends on whether ruptures are repaired. Repaired ruptures predict better outcomes than alliances that never ruptured at all.

Tronick's still-face paradigm shows the same in infancy: interaction is a continual mismatch-and-repair cycle, and normal development runs on the repair rather than on the match. Gottman's marital work found repair attempts to be the discriminating variable.

The turn. A relationship is not a state that is good or bad. It is a pattern held together by continuous repair, and its quality is the repair capacity, not the absence of damage.

Depth and form here. Depth explains why this is therapeutic at all. A person is a deep knot; talking is a shallow, fast layer. Therapy works when repair at the fast layer reaches a layer slow enough to matter, which is why it takes time that cannot be compressed — the deeper layer runs slower and cannot be repaired faster than it turns.

Form is what is being repaired into: the class the pattern is being laid back toward.

What follows. The dose-response curve in psychotherapy, which flattens rather than rising indefinitely, becomes expected rather than puzzling. Repair rate is bounded, and depth sets how much can be reached per unit time.

And relapse stops being failure. A pattern that is no longer being re-laid at the rate its size requires returns toward the class it can maintain.

XI. Social Psychology of Close Relationships

The accepted starting point. Closeness can be measured, and the measurements predict whether relationships continue.

Where it stalls. What closeness is remains unspecified. It is measured as a report, a behaviour frequency, or an overlap, and treated as a latent quantity that these index.

What the field already measures. Aron, Aron and Smollan built an instrument of seven pairs of circles, from just touching to almost completely overlapping, on which respondents indicate how much another is included in their sense of self. It has been in use since 1992, and greater overlap goes with greater commitment.

An extended interactive version, IOS11, was published by Baader, Starmer, Tufano and Gächter in 2024.

The turn. The instrument measures an overlap fraction: how much of what was each person's boundary has become shared. That is not a metaphor for closeness. It is a quantity in the model, and it is the one that governs how long a pair holds.

Depth and form here. Depth: a pair is a knot over two knots. Its retention exceeds either member's and its hold is looser, because what it closes over is already deeply closed and keeps most of its boundary to itself.

Form: which shared connections, in what arrangement.

What follows. Closeness stops being a gradient. Two people form a further knot when their joint repair gets round their joint pattern, and do not when it does not. Below the threshold there is contact without closure — a distinct state rather than a weak version of the same one.

And the measurement should be taken as a curve. Shared boundary rises during interaction and decays after it. A single reading after the fact samples one point on that curve.

XII. Economics

The accepted starting point. Firms exist. Coase asked why, given that markets could in principle coordinate everything, and answered by transaction costs. The question has never stopped being live.

Where it stalls. Transaction costs say why a boundary is drawn. They do not say what the firm is on the inside of it, nor why a firm persists while every employee, product and market position changes.

What the field already measures. Nelson and Winter's evolutionary theory made routines the unit and stated the crucial property: a routine is organisational memory, and it is remembered by being exercised. A routine not performed is lost. Skill decays without practice, at the level of the organisation as much as the individual.

Ostrom's work on common-pool resources found, across hundreds of cases, that durable institutions share design features — and monitoring and graduated sanctions are among them. Institutions that persist are the ones that pay for continuous checking and correction.

The turn. A firm is not a set of contracts and not a stock of assets. It is a pattern of routines that persists because it is continually performed, and it stops when the performing stops.

Nelson and Winter said this. Ostrom measured the price of it.

Depth and form here. Form is which routines and their arrangement: what makes this firm this firm and not a competitor with identical assets. Depth is the ladder from individual skill through team routine, departmental process, firm-level capability, to sector convention.

What follows. Ostrom's monitoring principle stops being one design feature among eight and becomes the repair capacity, which is the quantity that decides whether the institution closes at all.

Capabilities gain a decay rate. A dynamic capability not exercised does not sit in reserve. It lapses on a schedule.

And an acquisition that keeps the assets and dismantles the coordination machinery has not bought the firm. It has bought the material of a knot that is no longer being laid.

XIII. Institutional Economics and Political Economy

The accepted starting point. Institutions are the rules of the game and they shape economic outcomes. North's formulation is the field's common ground.

Where it stalls. North distinguished formal rules from informal constraints and observed that the informal ones change slowly and dominate outcomes. Why they persist he described rather than explained. Path dependence names the phenomenon.

What the field already measures. Institutional change research finds that formal rules can be rewritten overnight and fail to take, while informal constraints survive regime change, occupation and constitutional replacement. Transplanted legal codes fail where they are not matched by existing practice.

The maintenance is visible where it lapses. State capacity research measures the cost of keeping a rule in force — inspectors, registries, courts, records — and finds that rules without that expenditure become nominal.

The turn. An institution is not a rule. It is a pattern of expectations and actions that persists because it is continually re-enacted, and a rule is a written summary of it. Writing the summary and stopping the enactment leaves nothing behind.

Depth and form here. Form is which expectations, in what arrangement. Depth is the nesting from household practice through local convention, sectoral norm, national law, to international regime, each slower than the one below.

What follows. Path dependence gains a mechanism. What persists is what is being laid again, and the deeper layers are laid more slowly and therefore change more slowly. That is not inertia; it is retention time, and it is a quantity.

Institutional reform gains a criterion. A reform holds if the re-enactment reaches the depth it targets. Rewriting a rule reaches the shallowest layer, which is why it so often does not take.

XIV. Organisation Studies

The accepted starting point. Organisations are processes rather than things. Weick's insistence on organising as a verb is now the field's default, taught before anything else.

Where it stalls. If organising is a verb, what is the noun? The field's honest position is that there isn't one, which leaves it unable to say what makes today's organisation the same organisation as last year's.

What the field already measures. Weick and Roberts studied flight-deck operations and described collective mind as heedful interrelating, existing only in the ongoing activity and vanishing when the activity lapses. Their central observation is that reliability comes from continuous mutual adjustment, not from having got the structure right.

Feldman and Pentland reconceived routines as having both an ostensive and a performative aspect, and showed empirically that the routine exists in its performances and that each performance changes it slightly.

High-reliability organisation research finds the same: reliability is a continuous accomplishment, and it degrades within days when attention lapses.

The turn. An organisation is a pattern of connections held by continuous performance. Feldman and Pentland's performative routine, Weick's organising and Weick and Roberts' collective mind are three names for it.

Depth and form here. Form is which routines and interdependencies: the pattern that survives when people leave. Depth is the layer count — pair, crew, unit, division, firm — and it is why reorganisations at the top so rarely reach the bottom. They change a slow layer, and the fast layers below go on being laid as before.

What follows. Organisational forgetting gains a rate. Capability is lost at the speed at which it stops being performed.

Redundancy stops being waste. Slack is where repair runs, and an organisation optimised to zero slack has removed the phases in which its own pattern is put back.

XV. Political Science and State Formation

The accepted starting point. States vary enormously in their ability to make things happen in their own territory, and this variation is not explained by formal constitutional design.

Where it stalls. State capacity is measured by proxies — tax take, census coverage, birth registration, road density — and the field is clear that these are indicators of something rather than the thing.

What the field already measures. Tilly's account of European state formation traces the machinery: censuses, registries, standing bureaucracies, surveys, courts. What all of these do is establish and continually renew a connection between the centre and each unit in the territory. A census not repeated becomes worthless within a decade; a registry not updated becomes fiction.

Scott's work on legibility describes the same apparatus from the other side, and notes that legibility is not achieved once but must be maintained against continuous drift.

The turn. A state is a pattern of connections between a centre and a population, maintained by continuous re-establishment. Its capacity is its repair rate, and its extent is how much pattern that rate can get round.

Depth and form here. Depth: household, village, district, province, state, federation. Form: which connections are maintained — a state that registers births but not land holds a different pattern from one that does the reverse, and the difference shows in what it can do.

What follows. State collapse gains an ordering. When repair capacity falls, the largest pattern fails first: the deepest layer, with the longest retention, goes before the shallower ones. The state before the province, the province before the village, the village before the household. That ordering is historically testable, and the reverse is excluded.

XVI. Law

The accepted starting point. A corporation is a person in law. It can own, contract, sue, be sued, and persist indefinitely while every shareholder, director and employee is replaced. This is not a metaphor in legal practice; it is the operative rule.

Where it stalls. What the corporate person is has never been settled. Fiction theory says the law pretends. Realist theory says the group exists and the law recognises it. Aggregate theory says it is shorthand for the members. All three remain in the textbooks because none defeats the others.

Maitland, who translated Gierke and knew the German literature better than anyone writing in English, set the problem out and declined to solve it. He observed that English law had managed the corporation sole and the trust by devices that make no theoretical sense and work.

What the field already measures. Legal practice measures maintenance precisely. A company persists by filing: annual returns, accounts, registered office, register of members. Cease filing and it is struck off — dissolved for failure to maintain, not for failure to trade. A trademark lapses without use. Possessory title is lost by non-use and gained by continuous occupation. Adverse possession is the law's own statement that a right is what is continually exercised.

The turn. The corporate person is neither a fiction nor a discovered substance. It is a pattern of connections maintained by continuous re-enactment — filings, meetings, resolutions, records — and it exists while that maintenance runs.

The law has always known the operational test. It strikes companies off for not filing.

Depth and form here. Form is the constitutional pattern: which organs, which powers, in what arrangement. Depth is the ladder from natural person through partnership, company, group, holding structure, to state, each with its own retention and its own maintenance requirement.

What follows. The three theories are three descriptions of the same object at different depths, and the question they fought over is answered by a threshold rather than by an ontology. The corporation exists while the filing gets round the pattern.

Piercing the corporate veil, which courts do case by case without a general rule, becomes a question about whether a separate closure was ever maintained.

XVII. Archaeology

The accepted starting point. Material culture persists and can be excavated, and it changes over time in patterned ways.

Where it stalls. The relation between the material and the society is the field's permanent problem. Pots are not people, and the field has spent fifty years saying so without settling what the pots are.

What the field already measures. Hodder's entanglement argument states the finding: things require continual care. A house needs roofing, a field needs weeding, a wheel needs a wright, a metal tool needs a smith and ore and fuel. Each thing that is kept creates dependence on the labour that keeps it, and on the other things that labour requires.

The archaeological record is largely a record of maintenance and its cessation. Abandonment layers, roof collapse, silted channels, unrepaired walls.

The turn. A material assemblage is not a set of objects. It is a pattern of connections between people, materials and practices, held together by continuous maintenance, and what excavation finds is that pattern at the moment the maintenance stopped.

Depth and form here. Form is which dependencies, in what arrangement: what makes this assemblage this culture. Depth is the ladder from tool through household, settlement, region, to network of regions, each with its own turnover.

What follows. Collapse gains an ordering rather than a cause. Entanglement research already observes that societies do not fail at the point of greatest stress but at the point of greatest maintenance burden. The deepest, most maintained pattern fails first, and the household outlasts the palace. That is a testable ordering across collapse horizons.

XVIII. Demography

The accepted starting point. A population persists while every individual in it is replaced. Nobody in a population of 1900 is in the population of 2000 and the population is continuous.

Where it stalls. The field treats this as arithmetic rather than as a problem, and it is a problem: what is the population, if not its members?

What the field already measures. Renewal theory answers precisely. Lotka's stable population theory shows that a population with fixed birth and death rates converges on a stable age structure independent of its starting composition, and that the structure persists while every cohort passes through it.

The field measures replacement directly. Total fertility below the replacement threshold and the pattern shrinks, however healthy the individuals.

The turn. A population is a pattern maintained by replacement, and the stable age structure is what persists while nothing in it does. Lotka proved this in the nineteen-twenties.

Depth and form here. Form is the structure: age distribution, kinship configuration, household composition. Depth is household, kin group, community, population.

What follows. Demography's central object turns out to be the cleanest formal instance of the model in the human sciences, with the mathematics already done. The renewal equation is a re-laying equation, and the replacement threshold is a maintenance threshold.

Which suggests the transfer runs the other way here. The renewal formalism is available to any field in this book that has a replacement process and no equations for it.

XIX. Urban Studies and Infrastructure

The accepted starting point. Cities and infrastructures persist over centuries while their material is entirely replaced. A road is resurfaced, a pipe relined, a building refitted, and the street is the same street.

Where it stalls. Planning theory treats infrastructure as built and then existing. The maintenance is treated as an operating cost.

What the field already measures. There is a specialisation whose entire subject is this. Star's ethnography of infrastructure established that infrastructure is invisible until it breaks, and that its normal condition is continuous repair. Graham and Thrift argued that repair and maintenance, not innovation, are the ordinary state of the built world and the principal activity within it.

The measurements exist in engineering: asset deterioration curves, renewal rates, backlog. A network of water mains has a computable replacement rate below which the system loses more than it renews, and the figure is used by utilities.

The turn. A city is not built and then present. It is a pattern of connections continually re-laid, and what is called an asset is a place where re-laying is currently happening.

Maintenance studies said this. Utilities compute it.

Depth and form here. Form is which connections: this street pattern, this network topology. Depth is the ladder from component through system, district, city, to region.

What follows. Infrastructure failure gains a threshold instead of an age. A system fails when renewal falls below what the pattern requires, and the failure will appear first in the deepest, most connected layer.

And the political economy of deferred maintenance becomes legible as something other than short-termism. Deferring maintenance does not postpone a cost. It moves the system out of the range where it holds.

XX. History and Cultural Memory

The accepted starting point. Societies remember things no living person witnessed, and the memory is selective, shaped and durable.

Where it stalls. Where the memory resides is unresolved. Halbwachs placed it in the group, which relocates rather than answers. Nora's lieux de mémoire place it in sites, which cannot account for the sites' own meaning changing.

What the field already measures. Assmann's distinction between communicative and cultural memory rests on a measurement: communicative memory, carried by living contact, reaches about eighty years and then stops. Beyond that, anything that persists is carried by institutions of repetition — festival, liturgy, canon, recitation, monument with ritual attached.

That is a decay curve with a maintenance threshold, established from comparative material.

The turn. Cultural memory is not stored in a group or a site. It is a pattern re-laid by repeated performance, and the eighty-year horizon is where one re-laying mechanism ends and another must take over or nothing survives.

Depth and form here. Form is which events, connections and meanings. Depth is the ladder from personal recollection through family memory, communal, national, to civilisational, each with its own re-laying cycle — daily, annual, generational.

What follows. The canon gains a function that is not political in the first instance. A canon is the repair schedule: the list of what gets re-laid and how often.

And forgetting gains a rate rather than a cause. What is not on the schedule goes on a timetable set by how often it was laid.

XXI. Ritual Studies

The accepted starting point. Ritual is repetitive, formal, and found everywhere. Its ubiquity is not disputed and its function is.

Where it stalls. Functional explanations — solidarity, anxiety management, signalling — all explain some rituals and not others, and each has counterexamples the field knows well.

What the field already measures. Rappaport's analysis makes liturgical order the unit and observes that its content is invariant while its performers change; the order persists because it is performed, and performing it is what constitutes the participant as a participant.

Whitehouse's modes of religiosity is built on a measured trade-off between frequency and intensity: doctrinal modes run on high-frequency, low-arousal repetition, imagistic modes on rare, high-arousal episodes. Both are re-laying schedules, and the field found the trade-off empirically before it had a reason for it.

The turn. A ritual is the maintenance operation of a knot at a depth above the individual, and its schedule is set by the retention time of the layer it maintains.

Depth and form here. Depth explains the frequency finding directly. Shallow, fast layers need frequent, low-intensity re-laying. Deep, slow layers need rare, high-intensity re-laying, because they turn over slowly and a single laying holds for long.

Form is the invariant sequence: what has to return for this to be that rite.

What follows. Whitehouse's two modes stop being two kinds of religion and become two depths of one operation, with intermediate cases predicted rather than accommodated.

And the observation that ritual is resistant to rationalisation gains a reason. Trimming a rite reduces the pattern that gets laid, which is the entire point of performing it.

XXII. Ethnomusicology and the Study of Entrainment

The accepted starting point. Musical traditions persist for centuries without notation, and collective music-making requires performers to lock to a common pulse without a conductor.

Where it stalls. How a tradition without notation stays the same tradition is the field's version of the transmission problem. And why entrainment happens at all — why bodies fall into phase — is a question the field measures and does not explain.

What the field already measures. Clayton, Sager and Will set out entrainment as a concept for musicology, drawing on the physics of coupled oscillators: independent rhythmic processes with their own periods that lock when weakly coupled. The phenomenon is measured directly, in ensembles, in audiences, and between performer and listener.

Crucially, entrainment is a phase relation and not an amplitude one. Weak coupling suffices. Strength is not the variable.

The turn. A musical performance is a set of knots coming into phase, and a tradition is a pattern re-laid by performance. Phase, not force, is what makes something stay.

Depth and form here. Depth is the metrical hierarchy the field already notates — subdivision, beat, bar, phrase, section, piece — with each level running at a fixed ratio to the one below. The ratios are small integers, and this is not a stylistic convention but a structural fact about nested cycles.

Form is which pattern: what makes this a raga, that a maqam, this a tune.

What follows. Entrainment stops being an import from physics used as a metaphor and becomes the general mechanism by which anything is retained. What returns in phase stays.

Which makes musicology, unexpectedly, the field with the best-developed vocabulary for the coupling mechanism the rest of this book needs.

XXIII. Education and the Science of Learning

The accepted starting point. What is learned is forgotten unless it is revisited. Ebbinghaus measured the curve in 1885 and it has never been overturned.

Where it stalls. Education is organised almost entirely around acquisition. The forgetting curve is acknowledged and the institution is not designed around it.

What the field already measures. The spacing effect is among the most robust findings in psychology. Cepeda and colleagues' meta-analysis established that distributed practice beats massed practice, and that the optimal gap scales with the retention interval required: the longer you need it to last, the wider the spacing must be.

That is a maintenance schedule with a rate, matched to a required retention time.

Bjork's work on desirable difficulties adds that retrieval — the act of laying it again — strengthens far more than re-exposure does.

The turn. Knowledge is not stored and retrieved. It is re-laid, and it holds as long as the schedule of re-laying gets round the pattern.

Depth and form here. Depth is the reason expertise takes years and cannot be compressed. A skill closed over sub-skills runs slower than any of them and can be laid only at its own rate. This is why deliberate practice has an irreducible duration.

Form is what makes this competence this one.

What follows. Curriculum gains a computable structure. The quantity of knowledge maintained sets the amount of revisiting required, and the ratio is fixed. A curriculum that increases content without increasing revisiting is not more ambitious; it is outside the range where the pattern holds.

And the finding that students forget most of a course within a year stops being a scandal and becomes arithmetic.

XXIV. Archives, Preservation and Digital Curation

The accepted starting point. Nothing is preserved by being left alone. Every conservator knows this; it is the first principle of the discipline.

Where it stalls. Preservation theory is well developed for objects and was thrown into disarray by digital material, where the object has no stable substrate at all.

What the field already measures. Rothenberg's argument that digital documents last only as long as the process that keeps migrating them reframed the field. The response, LOCKSS — lots of copies keep stuff safe — is not storage. It is continuous comparison, detection of divergence, and restoration from peers. Bit rot is real and measured; integrity is maintained by scheduled auditing.

Preventive conservation for physical collections works the same way: monitor, detect drift, intervene, repeat.

The turn. An archive is not a store. It is a pattern maintained by continuous checking and restoration, and a document that is not being checked is not being preserved.

The field arrived at this by necessity, and named its systems accordingly.

Depth and form here. Form is the bit pattern, or the physical structure, that must return. Depth is the ladder from bit through file, format, collection, to repository — each with its own failure mode and its own audit cycle.

What follows. The distinction between original and copy loses its footing, which the field has already conceded in practice. What persists is the class, not the material — the same conclusion reached from cell biology and oral tradition.

And this specialisation supplies the others with a worked engineering vocabulary: audit rate, integrity check, restoration from redundancy, and the calculation of how much redundancy a given loss rate requires.

Part Two — The Life Sciences, Medicine, and the Formal Sciences

Part One walked twenty-four disciplines of the human and social sciences from their own accepted ground to a single object. This part does the same for the life sciences, medicine, and the formal sciences, using the same six steps in each chapter.

The life sciences will find this least surprising, because several of them have been working on it for decades under their own names.

XXV. Biochemistry and Proteostasis

The accepted starting point. The molecular constituents of an organism are continuously replaced. Schoenheimer's isotope work in the nineteen-thirties established this and no result since has qualified it.

Where it stalls. If the material is replaced, what is the organism? Biochemistry answers with organisation, structure or information, and none of these is located.

What the field already measures. The field has its own word and its own subfield. Proteostasis — protein homeostasis — is the network of synthesis, folding, chaperoning, trafficking and degradation that keeps the proteome in the state it is supposed to be in. Balch and colleagues set out the concept as a therapeutic target: the disease is a failure of maintenance, not of a component.

Turnover rates are tabulated across the proteome and span minutes to years. Degradation is not damage; it is scheduled, and the schedule is part of the maintenance.

The turn. A living cell is not a set of molecules and not a structure that happens to be repaired. It is a pattern of relations that exists because the network keeps laying it again, and the molecules are what the laying uses.

Proteostasis is not a mechanism that protects the cell. It is what being a cell consists of.

Depth and form here. Form is which relations are maintained: this proteome and not another. Depth is the ladder from molecule through complex, organelle, cell, tissue, to organism, and turnover rate falls at each step.

What follows. Proteostatic collapse in neurodegeneration and ageing stops being one pathology among many and becomes the general form of failure: the pattern outgrows what repair can get round.

And the field's own numbers give the ratio. Repair rate over decay rate is computable from turnover and error data, and it bounds how large a maintained pattern can be.

XXVI. Molecular Genetics and the Error Threshold

The accepted starting point. Genomes are copied with errors, and error rates are measured with precision.

Where it stalls. Why genome sizes are what they are is not fully settled, and the relation between fidelity and size is treated as one factor among several.

What the field already measures. Eigen established the error threshold in 1971: an inverse relation between the size of a replicating molecule and its error rate, with the product of per-base error rate and genome length bounded below one. Longer than that and information is lost faster than it is restored, however fast replication runs.

The numbers are in the literature. A typical RNA virus has a genome of about 10^4 bases and a mutation rate of about 10^{-4} errors per base per round of replication — the product is of order one, and the virus sits at the threshold. In humans, polymerase selectivity, proofreading and post-replicative mismatch repair together bring the rate to roughly one error per 10^9 to 10^{10} base pairs per division, against a haploid genome of 3.2×10^9 bases. The genome sits inside the measured range of its own bound.

Orgel's error catastrophe of 1963 is the same inequality read toward failure.

The turn. The largest maintained pattern equals the ratio of repair to decay. Molecular genetics established this for one kind of pattern fifty-five years ago and has not generalised it.

Depth and form here. Form is the sequence. Depth is why the bound differs by organism: proofreading is a closure over polymerase fidelity, and mismatch repair a closure over that. Each added layer multiplies the bound, which is exactly why large genomes carry machinery that small replicators do not.

What follows. This is the one place in this book where the model's central inequality has been checked against measurement by an independent route, and it holds. That is not evidence for the untested chapters. It is evidence that the machinery is not broken.

XXVII. Cell Biology

The accepted starting point. A cell has a boundary, and the boundary is not a static wall. Membrane is synthesised, inserted, internalised and degraded continuously; the cell is the same cell throughout.

Where it stalls. What makes the cell one thing is the field's oldest question. Compartment, boundary and organisation are the available answers and each presupposes the thing it explains.

What the field already measures. Maturana and Varela's autopoiesis gives the most developed answer: a living system is a network of processes that produces the components that produce the network, and that produces its own boundary. Luisi's chemical work made this experimentally approachable in vesicle systems.

Membrane turnover, endocytic recycling and lipid flux are measured routinely. The boundary is a rate, not a wall.

The turn. Autopoiesis and the knot describe the same object. The difference is that autopoiesis is a category — a system is autopoietic or it is not — while the knot is a quantity, with two numbers and a bound.

That difference is why autopoiesis had to be extended to other levels by declaration rather than by counting, and why the extensions have remained contested.

Depth and form here. Form is which relations must be produced for this to be this cell. Depth is what autopoiesis lacks: it has no way to say that a tissue is the same kind of thing as a cell, one closure up, so the extension to multicellularity has to be argued rather than derived.

What follows. Boundary stops being a primitive. It is the open connections, and closure is the taking-in of connections. From which follows a statement autopoiesis cannot make: complete closure, with nothing left open and nothing passing through, is death rather than maximal stability.

XXVIII. Immunology

The accepted starting point. An immune system distinguishes self from non-self, and it does so without a stored list of self-components. This is not disputed; what it means is.

Where it stalls. The self–non-self frame has known failures: tolerance of gut flora and foetus, autoimmunity, transplant behaviour. Matzinger's danger model replaced the question rather than answering it, and the field now works with several partial frames.

What the field already measures. Jerne's idiotypic network theory proposed that the immune system is a network of receptors recognising one another, so that self is defined by the network's own ongoing state rather than by a list. The theory fell out of favour for specific reasons, and the underlying observation did not: immune identity is maintained dynamically, by continuous interaction, and it drifts.

Tolerance is measured as an active, continuously maintained state. It lapses when the maintaining populations are removed.

The turn. Immune self is a pattern of relations maintained by continuous interaction. It is not a list and not a boundary. It is a knot, and tolerance is its maintenance.

Jerne was working on the right object with the wrong formalism.

Depth and form here. Form is the specific pattern — which relations count as self in this organism. Depth is receptor, clone, repertoire, tissue-resident population, systemic network.

What follows. Autoimmunity becomes a re-laying failure rather than a mistake in recognition: the pattern is being laid outside its class. That is a different research question from "what is misrecognised".

And the microbiome's tolerance stops being an exception. The flora are inside the maintained pattern, which is the next chapter.

XXIX. Microbiome Research and Holobiont Biology

The accepted starting point. A human body contains vast microbial populations in continuous material and signalling exchange with it, and the exchange is not optional. Removing it produces a sick animal.

Where it stalls. Where the individual ends. Gilbert, Sapp and Tauber put the conclusion in their title: we have never been individuals.

What the field already measures. The exchange is measured directly — metabolites, immune signalling, colonisation dynamics. And the composition is unstable: it shifts with diet, illness and antibiotics, and it recovers, partially, on a measurable timescale.

What is stable is not the species list. Functional profiles are more conserved across individuals than taxonomic ones.

The turn. The boundary question dissolves once the individual is a knot rather than a container. The boundary is where connections are open, and open connections do not mark the end of the thing; they are how it runs.

The holobiont is not a larger individual that replaces the smaller one. It is a closure at greater depth, and the human knot inside it is still a knot.

Depth and form here. Depth is the whole point here, and it is what the holobiont debate lacks. Asking whether the individual is the human or the holobiont is asking which depth is the real one. Both are, at their own depth.

Form is which relations are maintained, which is why functional profiles conserve while species lists do not: form is the pattern of relations, not the material occupying it.

What follows. Dysbiosis gains a definition that is not statistical deviation from a reference population. It is a maintained pattern falling out of its class.

XXX. Neuroscience

The accepted starting point. Memory persists for decades. The molecules constituting synapses turn over in days to weeks. Crick posed the problem in 1984 and it has not gone away.

Where it stalls. The standard answer is that the pattern of connectivity is the memory and the molecules are replaceable. This works until the connectivity is measured over time.

What the field already measures. Representational drift. Chronic recording in behaving animals shows that the population code for a fixed stimulus or a well-learned task changes continuously — the cells that carry the representation today are not the ones that carried it a month ago — while behaviour is stable. Rule, O'Leary and Harvey set out the causes and consequences.

Synaptic turnover is measured directly: dendritic spines appear and disappear on a timescale of days in adult cortex.

Hasson and colleagues measured a hierarchy of temporal receptive windows, with the timescale over which information is integrated rising systematically up the cortical hierarchy.

The turn. Neither the molecules nor the connections are the stable thing. What is stable is the class the pattern is laid back into.

Drift is not noise degrading a stored representation. Drift is what re-laying looks like when you measure it.

Depth and form here. Depth is the temporal hierarchy Hasson measured, and the model says the ratios between adjacent levels are ratios of small whole numbers rather than arbitrary factors. The data to check this already exist.

Form is the class: what makes this memory this one across substrate that has fully turned over.

What follows. Consolidation stops being transfer from one store to another and becomes re-laying at a deeper, slower layer. Which explains why it takes the time it takes and cannot be accelerated: a slower layer cannot be laid faster than it turns.

And sleep gains a structural role that is not restorative in the loose sense. Repair runs where nothing is flowing through.

XXXI. Medicine

The accepted starting point. Health is not the absence of damage. Damage occurs continuously and is continuously repaired, and health is the capacity to keep doing so.

Where it stalls. The field has no single quantity for that capacity. Homeostasis, reserve, resilience and allostatic load are four partial names, and clinical practice proceeds mostly by treating components.

What the field already measures. Both rates exist in the literature and are never divided by one another.

Decay is measured: deconditioning curves for muscle, bone and glucose tolerance; the Dallas bed rest studies quantified loss of capacity over weeks of immobility with precision.

Repair is measured: wound healing rates, fracture union times, sleep-dependent consolidation, post-exertional recovery.

Their ratio is not a quantity in medicine. It has never been computed.

The turn. Health is the ratio of repair rate to decay rate, and the largest pattern a body can maintain equals that ratio.

Disease is then not primarily a broken component. It is a pattern no longer getting re-laid at the rate its size requires.

Depth and form here. Depth is why interventions at one level do not reach another, and why a fast intervention cannot repair a slow layer. Form is what makes this patient this patient — the pattern that is being maintained, which is not the same set of diagnoses in two people with the same list.

What follows. Rest gains a required size rather than a recommendation: the fraction of the pattern that repair must get round per cycle. It rises with the number of maintained functions, not with exertion.

And the failure mode is precise. Repair runs only where throughflow approaches zero. If those phases are prevented, the achieved rest falls below the requirement however modest the load —

which predicts that sustained low demand is more damaging than alternating high demand at equal total. That is testable in shift work, continuous availability, and intensive care.

XXXII. Gerontology

The accepted starting point. Ageing is not a programme of destruction. It is a decline in the ability to maintain.

Where it stalls. Which maintenance, and why it declines, remains open, and the field carries several theories at once.

What the field already measures. Kirkwood's disposable soma theory states the argument in the model's own shape: an organism allocates finite resources between reproduction and somatic maintenance, and ageing is the accumulated consequence of investing less in maintenance than would be required for indefinite persistence.

Frailty indices count maintained functions and their loss, and predict outcomes better than any single organ measure.

The turn. Ageing is the repair-to-decay ratio falling. Everything else follows from that one quantity.

Kirkwood said this in 1977 in evolutionary terms. The model says it as an inequality with a bound.

Depth and form here. Depth gives the ordering, and the ordering is the prediction. As the ratio falls, the largest maintainable pattern shrinks, and the largest patterns sit at the greatest depth. So loss proceeds from the top down: the slowest, most integrated, longest-retention level fails first, while shallower levels remain within their own windows.

What follows. Frailty indices should show that ordering, and they are the instrument to test it with.

And the required rest fraction rises in proportion as the ratio falls. A fall of a third in repair capacity requires a rise of half in rest. That is a different claim from "older people sleep differently", and it is measurable.

XXXIII. Epidemiology

The accepted starting point. An epidemic persists only if each case produces at least one further case. The basic reproduction number is the field's central quantity.

Where it stalls. The framing treats the pathogen as the thing and the population as its medium. That works for acute infections and less well for endemic states, reservoirs and persistent low-level circulation.

What the field already measures. R itself is a re-laying rate. Above one the pattern is being laid faster than it lapses; below one it decays. The field's entire control apparatus is built on moving a maintenance ratio across a threshold.

Susceptible replenishment — the return of a susceptible population by birth and waning immunity — is the maintenance of the medium, and it sets the periodicity of recurrent epidemics.

The turn. An endemic disease is a knot: a pattern of transmission connections maintained by continuous re-laying in a population, with a threshold below which it does not close.

Depth and form here. Form is which transmission connections: the contact structure, which is why network epidemiology outperforms mass-action models. Depth is pathogen, host, household, community, region.

What follows. Elimination and eradication gain a shared account with everything else in this book: a pattern stops when re-laying falls below what its size requires.

And the model runs the other way too. The epidemiological apparatus — reproduction numbers, thresholds, susceptible replenishment — is the best-developed mathematics of re-laying anywhere in the life sciences, and it is available to the other chapters.

XXXIV. Psychiatry

The accepted starting point. Psychiatric disorders are defined by symptom clusters, and the clusters are stable enough to be diagnosed reliably while the underlying biology has resisted identification.

Where it stalls. The latent disease entity that was supposed to explain the cluster has not been found for any major disorder. Decades of biomarker work have not produced one.

What the field already measures. Borsboom's network theory of mental disorders takes the symptoms themselves as the system: symptoms cause and sustain one another, and a disorder is a self-sustaining pattern of symptom connections rather than the effect of a hidden entity. Network models predict hysteresis — a state that persists after the trigger is gone — and empirical network analyses of symptom data are now routine.

The turn. A disorder is a knot: a pattern of connections that maintains itself. Not a thing behind the symptoms, and not a mere label for their co-occurrence.

Borsboom's network theory is this proposal, made in psychiatry, without depth.

Depth and form here. Form is which symptom connections, in what arrangement: what makes this person's condition this one rather than a diagnostic category.

Depth is what the network theory does not have and needs. A symptom network sits on one plane, and psychiatry's phenomena manifestly do not: a physiological rhythm, a habit, a mood, a self-concept and a social role are at different depths, and interventions reach different depths.

What follows. Treatment resistance gains an account. An intervention at a fast layer cannot repair a slow one faster than that layer turns.

And relapse becomes expected rather than anomalous: a pattern being laid at less than its required rate returns toward the class it can maintain.

XXXV. Rehabilitation and Exercise Physiology

The accepted starting point. Capacity not used is lost, and the loss is fast. This is the operating principle of the entire discipline.

Where it stalls. The mechanisms are studied tissue by tissue, and there is no single account of why the pattern holds when it holds.

What the field already measures. This field has the cleanest decay data in medicine. The Dallas bed rest study measured cardiovascular capacity before and after three weeks of bed rest and found losses comparable to decades of ageing, reversed by training. Muscle mass, bone density, insulin sensitivity and balance all have measured disuse curves.

And the repair side is measured with equal precision: training adaptation rates, detraining rates, and the interval after which an adaptation is lost.

The turn. A physical capacity is not a possession. It is a pattern maintained by use, and its half-life without use is measurable.

The field knows this and states it as a slogan. It is an inequality.

Depth and form here. Form is which capacities are maintained. Depth is why the deepest capacities take longest to build and longest to lose, and why a fast intervention builds a shallow layer that lapses first.

What follows. Rehabilitation gains a computable maintenance dose: the rate of use below which the pattern is not held. That is currently prescribed by convention.

And this specialisation supplies medicine with the missing half of its ratio. It has decay rates for a dozen systems, measured. Dividing them by the corresponding recovery rates would produce the first repair-to-decay numbers for a human being.

XXXVI. Ecology

The accepted starting point. An ecosystem persists while every organism in it is replaced, and it maintains structure through continuous flows of energy and matter.

Where it stalls. Whether an ecosystem is a thing or a collection has been argued since Clements and Gleason, and the field has not settled it — the same dispute as sociology's, in another domain.

What the field already measures. Odum established throughflow as the organising quantity: ecosystems maintain structure only while energy passes through, and cease when it stops. Ulanowicz's ascendancy formalises the pattern of flows rather than the inventory of species.

Holling's resilience is measured as the capacity to reorganise after disturbance, and the field distinguishes it sharply from stability.

The turn. An ecosystem is a pattern of connections maintained by throughflow, and species are the material through which it is laid.

Ecology reached this in the nineteen-fifties and it remains one of the field's two competing frames.

Depth and form here. Form is the flow structure — Ulanowicz's insight, that the connections matter more than the inventory. Depth is organism, population, community, ecosystem, biome.

What follows. The Clements–Gleason dispute gains the same criterion as sociology's. An ecosystem exists as a thing when its joint maintenance gets round its joint pattern, and does not when it fails to. Both camps were right about different systems.

And collapse gains the same ordering as everywhere else in this book: the deepest and most connected pattern fails first.

XXXVII. Evolutionary Biology

The accepted starting point. Entities that once replicated independently have repeatedly become parts of larger wholes that replicate as units. Maynard Smith and Szathmáry set out the major transitions and the framing is standard.

Where it stalls. Why the transitions happened, and why there have been so few, is not settled. Each is usually explained by its own particular circumstances.

What the field already measures. The transitions have a common form, and the field states it: entities that could replicate independently before the transition can only replicate as part of the whole afterwards. Genes into chromosomes, replicators into cells, prokaryotes into eukaryotes, cells into multicellular organisms, organisms into colonies.

That is closure, described by evolutionary biology from its own material, with a list.

The turn. Each major transition is one closure. Depth is the count of them along a lineage, and the list is short because the tower is short.

Depth and form here. Depth: the transitions are the levels. The model adds that their number is bounded, and bounded by the repair-to-decay ratio.

Form: which connections became obligatory at each transition — the pattern that has to be maintained for the new unit to be a unit.

What follows. The scarcity of major transitions stops requiring a separate explanation for each. There are few because each closure multiplies the pattern to be maintained while the bound does not move, and the tower runs out.

And the transitions and the error threshold, currently two separate discussions in the same field, become one. Both are the same inequality: how much pattern can be held at a given ratio.

XXXVIII. Developmental Biology and Regeneration

The accepted starting point. Form is restored after damage without a stored blueprint being consulted. A planarian cut into pieces regenerates a complete worm from each piece, with correct proportion and polarity.

Where it stalls. Where the pattern information resides is one of the field's oldest unsolved questions. Positional information, morphogen gradients and bioelectric prepatterns are partial answers, and none locates a blueprint because there isn't one.

What the field already measures. Turing showed how pattern can arise from local interaction without a plan. Regeneration research shows the pattern being restored from a fragment that contains no representation of the whole. Work on bioelectric states shows that pattern-relevant information is held in a distributed, dynamically maintained physiological state rather than encoded in a store.

The turn. Form is not stored. It is the class the tissue keeps laying itself back into, and regeneration is re-laying resumed from a fragment.

This is the same conclusion as oral tradition, digital preservation and neuroscience reached in their own domains: what persists is the class, not the record.

Depth and form here. Form, here, is the field's own central term, and the model says what it is: the class into which the pattern is re-laid. Depth is cell, tissue, organ, organism, and it explains why regenerative capacity falls as depth rises. The deeper the pattern, the more there is to get round.

What follows. The blueprint search stops being a search for a missing store. There is no store to find, and the negative results are the finding.

And the loss of regenerative capacity in large, long-lived animals gains a quantity rather than a trade-off story.

XXXIX. Mathematics: Chord Diagrams and Knot Theory

The accepted starting point. A chord diagram — a circle with chords joining paired points — is a well-studied combinatorial object, and it is the combinatorial core of finite-type knot invariants.

Where it stalls. Nothing stalls. This chapter is not a bridge but a supply.

What the field already has. Two statistics are standard on a chord diagram. Two chords cross when their endpoints alternate around the circle; they nest when one lies wholly inside the other. Crossing number and nesting number are the two natural statistics, and Chen, Deng, Du, Stanley and Yan proved that their joint distribution is symmetric.

Crossings, not nestings, generate the genus of the associated ribbon surface: a diagram whose chords only nest is planar. So the two statistics do different geometric work.

Bar-Natan's work established chord diagrams modulo relations as the algebra underlying Vassiliev invariants.

The turn. The model's two quantities are these two statistics. Form is the crossing structure; depth is the nesting structure.

What follows. Every combinatorial result about crossings and nestings is a result about form and depth. The symmetry theorem says the two are on equal footing. Enumeration of k -noncrossing and k -nonnesting diagrams bounds the number of possible forms at a given complexity and the number of possible depths.

And knot theory supplies the classification. If living things are knots, then the alphabet of possible forms is a mathematical object that already exists and is partly tabulated.

XL. Physics

The accepted starting point. Persistent localised structures exist in continuous media, and some of them are stable for topological reasons rather than dynamical ones.

Where it stalls. The relation between such structures and matter itself is a minority research programme, and the mainstream treats particles as excitations of fields rather than as knots.

What the field already measures. Kelvin proposed matter as knotted vortex motion in 1867. Faddeev and Niemi demonstrated stable knot-like solitons in classical field theory carrying a conserved topological charge. Williamson and van der Mark proposed the electron as a closed circulation of light with toroidal topology.

Prigogine and Nicolis established dissipative structures: order that exists only while flow runs through it, in ordinary physics and chemistry.

Jacobson showed that a fixed background can be replaced by the thermodynamics of a medium.

The turn. A thing is a pattern that keeps coming back in a continuous medium, maintained by throughflow. Physics has each half of this and has not joined them: topological stability in one literature, dissipative maintenance in another.

Depth and form here. Form is the topological charge — the discrete invariant that makes a soliton this soliton. Depth is the nesting, which soliton physics does not currently count.

What follows. Dissipative structures gain an identity invariant, which they lack: a dissipative structure is currently defined by its dynamics and has no discrete label. Topological solitons gain a maintenance condition, which they lack: they are treated as stable rather than as maintained.

Joining them gives an object that is both discrete and maintained, which is what everything else in this book has turned out to be.

XLI. Distributed Systems and Computer Science

The accepted starting point. A distributed system's state is not stored anywhere in a way that stays correct. It is maintained by continuous message passing, and the maintenance is the system.

Where it stalls. Nothing stalls here either. This field has engineered the object and has the best operational vocabulary for it.

What the field already has. Dijkstra defined self-stabilization in 1974: a system that, from any arbitrary state, converges to a legitimate state and stays there without external intervention. That is re-laying, specified as an engineering requirement and proved for concrete algorithms.

The rest of the vocabulary follows. Heartbeats and leases: a connection that is not renewed expires. Gossip protocols: state maintained by continuous exchange rather than by a master copy. Garbage collection: scheduled removal of what is no longer part of the maintained pattern. Disk scrubbing: continuous verification and restoration from redundancy. Error-correcting codes: a bound on how much corruption a pattern can absorb and still be restored, which is the error threshold in another domain.

The turn. Nothing here needs turning. Distributed computing built the object deliberately because nothing else works at scale.

Depth and form here. Form is the state to be maintained. Depth is the layering the field builds routinely — packet, connection, session, service, cluster, region — with each layer's timeout a fixed multiple of the layer below, because a layer cannot detect failure faster than the layer beneath it reports.

That multiple is the tempo ratio, chosen by engineers because systems fail when it is violated.

What follows. This field supplies the others with worked engineering: audit rates, redundancy calculations, the relation between failure detection time and layer depth, and the proof that a legitimate state can be reached from an arbitrary one without external intervention.

And the model supplies a reading back. A distributed system is alive in the sense used in this book, and it fails in the same ordering: the deepest, most integrated layer first.

XLII. Cybernetics and Systems Theory

The accepted starting point. Systems maintain themselves against disturbance by regulation, and regulation requires variety at least equal to the variety of the disturbance. Ashby's law of requisite variety is the field's clearest formal result.

Where it stalls. Systems theory has levels and no rule for how many. Hierarchy is observed, named, and taken as given. Simon's near-decomposability describes the condition and does not derive it.

What the field already measures. Simon showed that hierarchically organised systems assemble and repair faster than flat ones, and that near-decomposability — strong interaction within levels, weak between — is what makes a hierarchy work. He derived the advantage of levels from the mathematics of assembly.

Beer's viable system model specifies recursion: each viable system contains and is contained in viable systems of the same form.

The turn. Beer's recursion is depth. Simon's near-decomposability is what closure produces: taking connections inward makes interaction within a level strong and between levels weak.

Both described the consequence without the operation.

Depth and form here. Depth is the recursion count, and the model adds the bound: the recursion terminates, because each level multiplies the pattern while the repair-to-decay ratio does not move.

Form is what makes this system this one, which cybernetics has traditionally abstracted away by design.

What follows. Requisite variety gains a companion. Ashby's law says the regulator must match the disturbance in variety. The model adds that the regulator must also get round its own pattern, and that this second requirement sets a ceiling on how much variety a regulator can have.

Which is why regulators fail by growing.

XLIII. Information Theory

The accepted starting point. Information can be transmitted reliably over an unreliable channel, up to a bound set by the channel. Shannon proved this in 1948.

Where it stalls. Storage is treated as a channel through time, which is correct and rarely taken to its conclusion.

What the field already has. Shannon's channel coding theorem sets a limit on rate given noise. Error-correcting codes achieve reliable retention over a noisy medium by continuous redundancy and correction, not by finding a medium that does not corrupt.

And the bound has the shape that recurs throughout this book: how much pattern can be held is set by the ratio between correction and corruption.

The turn. Storage through time is re-laying. There is no medium that simply holds; there is a rate of corruption and a rate of correction, and the maintainable pattern is bounded by their ratio.

Eigen's error threshold in genetics, disk scrubbing in distributed systems and Shannon's bound are three statements of one inequality in three domains, and only the last is proved in general form.

Depth and form here. Form is the message. Depth is the concatenation of codes, which the field uses routinely: an inner code corrected fast, an outer code corrected slowly, each layer handling what the layer below could not.

What follows. This is where the model's central inequality has its general proof. Information theory did not set out to characterise living things and produced the bound that governs them.

Which is the appropriate place for this book to end. The object it describes was not discovered by any of the disciplines in it. Each of them arrived at part of it while working on something else, and named it in its own language: repair, proteostasis, self-stabilization, relatedness, entrainment, soft assembly, routine, re-laying, maintenance.

They are one word.

Part Three — The Remaining Social, Applied and Technical Disciplines

Part One covered twenty-four disciplines of the human and social sciences; Part Two nineteen of the life, medical and formal sciences. This part covers twenty-two that were left out, several of which turn out to hold the cleanest cases in the entire work.

XLIV. Cultural Evolution and Transmission

The accepted starting point. Culture is inherited, and the inheritance is not genetic. Boyd and Richerson established the formal apparatus for treating it as a second inheritance system with its own dynamics.

Where it stalls. Why some cultural repertoires accumulate complexity and others lose it is not settled by the transmission mechanism alone.

What the field already measures. Henrich's analysis of the Tasmanian case supplies the finding. When the land bridge closed and the population was cut off, the toolkit did not stay put; it lost complexity over millennia. His model shows why: transmission is imperfect, most learners fall short of the model, and a repertoire is retained only if enough learners at high enough fidelity keep re-laying it. Below a population threshold, complexity is lost regardless of intelligence or need.

Sperber's epidemiology of representations makes the same point about individual items: a representation spreads and persists as a function of how reliably it is reproduced, not of its truth.

The turn. A cultural repertoire is a pattern maintained by transmission, and the amount of it that can be held is bounded by transmission fidelity times the number transmitting.

That is the error threshold, arrived at independently in anthropology, with its own models and a documented case.

Depth and form here. Form is which practices, in what arrangement. Depth is technique, craft, tradition, cultural complex.

What follows. Cultural loss stops needing a separate cause. It happens when the pattern exceeds what the transmitting population can re-lay, which is computable from group size and fidelity.

And this chapter and the chapter on molecular error thresholds are the same inequality with different substrates. Neither field cites the other.

XLV. Criminology and Desistance

The accepted starting point. Most people who offend stop. Desistance is the normal outcome, and it is age-graded.

Where it stalls. Why they stop is contested. Maturation, deterrence, identity change and opportunity all explain part of it.

What the field already measures. Hirschi's control theory made bonds the unit: attachment, commitment, involvement, belief. Offending rises when bonds are weak. Sampson and Laub's follow-up of the Glueck cohort into old age found that desistance tracks the acquisition of bonds that must be sustained — a marriage that is worked at, a job with obligations, ties requiring continuous investment.

The crucial detail in their data is that the bond has to be maintained. A marriage on paper does not predict desistance; a marriage that is invested in does.

The turn. A conventional life is a pattern of connections maintained by continuous investment. Desistance is the laying of that pattern; relapse is falling back to whatever pattern is still being laid.

Depth and form here. Depth explains why desistance takes years and why brief interventions fail. The pattern being built is deep and slow, and it cannot be laid faster than it turns.

Form is which bonds, in what arrangement.

What follows. Recidivism after release becomes expected rather than a failure of will or of programme design. Custody removes every connection that was being re-laid, and release returns a person to a place where the only pattern still being laid is the old one.

And the effectiveness of interventions gains a criterion: does the intervention establish connections that will keep being re-laid after it ends.

XLVI. Social Movement Studies

The accepted starting point. Movements have cycles. They mobilise, peak, and demobilise, and the demobilised period is not the absence of the movement.

Where it stalls. What survives between waves has been hard to specify. Resource mobilisation theory studies the mobilised phase best.

What the field already measures. Taylor's study of the American women's movement between the suffrage victory and the nineteen-sixties introduced abeyance structures: small, committed networks that maintain the movement's repertoire, personnel and identity through periods when mobilisation is impossible, and hand them to the next wave.

The finding is that continuity is achieved by a reduced structure doing continuous maintenance, not by dormancy.

The turn. A movement is a pattern maintained by continuous activity. In abeyance it is reduced to the smallest pattern its remaining capacity can get round, and it survives at that size.

Depth and form here. Form is the repertoire: which practices and framings are kept alive. Depth is affinity group, organisation, movement, movement family.

What follows. Abeyance stops being a special case and becomes the general behaviour of any knot under falling capacity. It sheds pattern down to what it can maintain, and the ordering is from the deepest layer down: the federation goes before the local chapter.

That is a testable ordering across movement declines.

XLVII. Organisational Ecology

The accepted starting point. Organisations die, and their death rates are patterned. Hannan and Freeman established that founding and mortality rates vary systematically with age, size and density.

Where it stalls. Structural inertia is the field's central mechanism, and it is defined negatively: organisations cannot change fast enough. Why they cannot is attributed to reproducibility and accountability requirements.

What the field already measures. This is the only branch of organisation research with hard survival data across whole populations. Stinchcombe's liability of newness — young organisations fail at higher rates — and the liability of smallness are both robust.

Hannan and Freeman's own explanation of inertia is instructive: what makes an organisation reliable is that its structure is reproducible, and reproducibility is exactly what makes it hard to change.

The turn. An organisation is a pattern being re-laid, and inertia is not a defect. Reproducibility is the re-laying, and an organisation is reliable to the degree that it re-lays the same pattern.

Depth and form here. Liability of newness gains an account: a young organisation has not yet closed. Its pattern is being laid for the first time, and until re-laying is established there is nothing to fall back into.

Liability of smallness likewise: a small organisation has less repair capacity relative to any pattern it holds.

What follows. The trade-off between reliability and adaptability stops being a tension to be managed and becomes an identity. They are the same quantity read in two directions, since both are the rate at which the same class is laid again.

XLVIII. Textual Criticism and Stemmatology

The accepted starting point. Manuscripts are copied with errors, errors are inherited, and the pattern of shared errors reveals the copying tree. Lachmann's method rests on this and it works.

Where it stalls. Contamination — copying from more than one exemplar — breaks the tree, and the field has argued about how to handle it since Bédier.

What the field already measures. This discipline measures copying fidelity directly, manuscript by manuscript, and reconstructs transmission over centuries from the error record. It knows what happens when copying stops: the text is lost, whatever its prestige. And it knows the survival rates — how many classical works are attested and how few survive.

A text persists only where a chain of copyists kept laying it again. The libraries that preserved most are the ones that copied most.

The turn. A text is not preserved by parchment. It is a pattern re-laid by copying, with a measured error rate, and it survives while the copying gets round it.

The same inequality as the genome and the cultural repertoire, in a field that has the error rates.

Depth and form here. Form is the text: which readings in which order. Depth is word, sentence, work, corpus, canon.

What follows. Contamination stops being an anomaly that breaks the method and becomes what re-laying normally looks like when more than one source is available — which is also the case in every other chapter of this book.

And this specialisation supplies the others with something they lack: centuries of measured fidelity data for a re-laying process with a known outcome.

XLIX. Heritage Studies and Conservation Theory

The accepted starting point. Authenticity is central to heritage and it is not the same as material originality. The 1994 Nara Document on Authenticity established this as international doctrine after the material-fabric criterion proved unusable outside Europe.

Where it stalls. If authenticity is not material, what is it? Nara answers with a list of attributes and the field continues to argue.

What the field already measures. The case that forced the change is the cleanest instance of the object in this entire work. The Ise shrine in Japan is dismantled and rebuilt on an adjacent site every twenty years, and has been for well over a millennium. Not one plank is old. The shrine is not a copy of itself, and every carpenter learns the craft by participating in the rebuilding.

The twenty-year cycle is not a preservation technique applied to the building. It is what the building is.

The turn. The heritage object is not the material. It is the pattern that is laid again, and the rebuilding cycle is its maintenance.

Nara reached this conclusion by being confronted with a case that could not be described otherwise.

Depth and form here. Form is the pattern that must return: proportion, joinery, orientation, sequence. Depth is joint, member, structure, precinct, and — crucially — the craft tradition, which is itself re-laid by the rebuilding.

What follows. The apparent paradox of a thousand-year-old building with no old material dissolves, and it dissolves in the same way as total molecular turnover in the body, drift in the cortex, and the recomposed epic.

And the rebuilding cycle stops being ritual attached to conservation. It is the mechanism by which the craft — the deeper knot — is maintained. Preserve the building and let the cycle lapse, and the deeper pattern is what is lost.

L. Game Theory and the Study of Cooperation

The accepted starting point. Cooperation is not stable in a one-shot prisoner's dilemma and is stable in the repeated game. This is a theorem, not an observation.

Where it stalls. Which strategies survive, and under what conditions, has generated an enormous literature and no single answer.

What the field already measures. Axelrod's tournaments established that the shadow of the future — the probability that the interaction continues — is the decisive parameter. Cooperation is sustained when the discounted value of continuation is large enough, and it collapses when the interaction is known to be ending.

Reciprocity is not a preference in these models. It is a structure that exists only in repetition.

The turn. A cooperative relationship is a pattern that exists only in being laid again, and the shadow of the future is the re-laying rate.

Game theory proved this and states it as a condition on parameters rather than as a property of relationships.

Depth and form here. Form is which reciprocal connections. Depth is the layering the field studies as indirect reciprocity and institutions: pair, group with reputation, institution with enforcement — each closing over the level below and holding longer.

What follows. The end-game effect gains a general reading. Cooperation collapses at the announced end of an interaction because re-laying stops, and this is the same behaviour as any other knot whose maintenance is withdrawn.

And the field supplies the others with the formal result: the threshold at which repetition sustains a pattern, proved.

LI. Social Epidemiology

The accepted starting point. Social connection predicts mortality. Berkman and Syme's Alameda County study found that people with fewer social ties died at higher rates over nine years, controlling for baseline health and behaviour, and the finding has replicated widely. Holt-Lunstad and colleagues' meta-analysis put the effect on a scale comparable to major established risk factors.

Where it stalls. Why a social tie should affect mortality is not settled. Stress buffering, behavioural pathways and inflammation are candidate mechanisms, and none accounts for the size of the effect.

What the field already measures. The measure that predicts is the number of ties actively maintained — contact frequency, participation, membership. Not ties nominally present.

The turn. A person is a knot, and its open connections are where flow enters. Fewer maintained connections means less throughflow, and a pattern is held only while something runs through it.

On this reading the effect is not mediated by stress or behaviour. It is the direct consequence of what maintenance is.

Depth and form here. Depth: the maintained connections at the social layer are what closes the person into anything above them. Someone with none is a knot at the top of a tower with nothing above.

Form: which connections, which is why the composition of a network predicts better than its size.

What follows. The mechanism question gains a candidate that is structural rather than physiological, and it makes a distinguishing prediction: the effect should track maintenance rate rather than reported closeness or perceived support.

That is measurable with instruments the field already uses.

LII. Science and Technology Studies: Metrology and Standards

The accepted starting point. A measurement is meaningful only through a chain of comparisons back to a standard. Traceability is the foundation of metrology, and no laboratory result stands without it.

Where it stalls. The philosophy of measurement treats the standard as fixed and the chain as a technical detail. It is neither.

What the field already measures. Every link in a calibration chain has an expiry. Instruments are recalibrated on a schedule; reference materials are revalidated; laboratories are reaccredited. A chain that is not renewed does not degrade gracefully — the result becomes inadmissible.

O'Connell's study of metrology describes the work of circulating particulars that makes universality possible, and Latour's account of metrological chains makes the same point: the universality of a unit is an achievement of continuous distribution and comparison, not a property of nature.

The turn. A unit of measurement is a pattern maintained by continuous re-comparison. Stop the comparisons and the unit does not persist in weakened form; it stops being a unit.

Depth and form here. Depth is the chain itself, and it is explicitly hierarchical: working instrument, laboratory standard, national standard, international definition, each maintained at a slower cycle than the one below.

Form is the specific network of comparisons.

What follows. The 2019 redefinition of the SI base units in terms of fixed constants reads, on this account, as an attempt to reduce the maintained pattern — replacing artefacts requiring continuous comparison with definitions requiring realisation. The maintenance did not disappear; it moved.

And metrology supplies the other chapters with the best-engineered instance of a maintained chain, complete with intervals, tolerances and the calculation of how uncertainty compounds along it.

LIII. Marketing and Brand Equity

The accepted starting point. Advertising effects decay. Stop advertising and sales decline on a measurable curve, and the industry models this explicitly as adstock decay with a half-life.

Where it stalls. What a brand is remains unsettled — an asset, a set of associations, a relationship, a mental availability. Each definition is used in a different part of the field.

What the field already measures. Both rates are measured routinely. Decay rates for advertising effects are estimated from sales data. Repeat-purchase patterns, following Ehrenberg's work, are stable and predictable, and depend on continued presence rather than on persuasion.

The industry's own practice reveals the assumption: brands are maintained by continuous expenditure, and the budget question is always the maintenance rate.

The turn. A brand is a pattern of associations maintained by continuous re-laying across a population, and brand equity is the size of the pattern that the current maintenance rate can hold.

Depth and form here. Form is which associations, in what arrangement. Depth is product, brand, portfolio, corporate identity, category — each slower and each harder to shift.

What follows. The perennial argument over whether advertising builds long-term equity or only drives short-term sales gains a resolution by depth. Fast spending lays a shallow layer that lapses fast; deep layers can only be laid at their own rate, over years.

And equity becomes computable rather than estimated: maintained pattern equals maintenance rate over decay rate.

LIV. Military Sociology and Unit Cohesion

The accepted starting point. Soldiers fight for their immediate group. Shils and Janowitz established, from interrogation of Wehrmacht prisoners, that combat motivation tracked the integrity of the primary group far more than ideology.

Where it stalls. Cohesion has resisted definition ever since. Task cohesion and social cohesion have been distinguished, correlated with performance, and argued over.

What the field already measures. The finding that matters is about replacement. Units that receive individual replacements into an existing formation perform worse than units rotated and reconstituted as wholes. This was learned expensively and changed doctrine.

Cohesion degrades on a measurable timescale when a unit is broken up, and it must be rebuilt through shared activity rather than assembled from qualified individuals.

The turn. A unit is a knot over its members. An individual replacement enters a maintained pattern and must be laid into it, which takes time and consumes repair capacity. Enough simultaneous replacements exceed what the pattern can absorb, and the knot loosens.

Depth and form here. Form is which connections in what arrangement: why a unit with the same roster on paper is not the same unit. Depth is fire team, squad, platoon, company, and the fact that cohesion is strongest at the smallest level is a statement that the shallowest layer is laid most often.

What follows. Rotation policy becomes calculable rather than doctrinal. The absorbable replacement rate is set by the unit's repair capacity relative to its pattern.

And this field supplies unusually clean evidence for a claim made throughout this book: the material can be fully replaced and the thing persists, but only if the replacement rate stays below the rate at which the pattern can be re-laid.

LV. International Relations and Regime Maintenance

The accepted starting point. International regimes persist after the conditions that created them have changed. Keohane's central argument is that regimes survive because maintaining them costs less than creating replacements.

Where it stalls. Why some regimes survive shocks and others collapse is explained case by case.

What the field already measures. The apparatus is visible and expensive: secretariats, review conferences, reporting requirements, inspection regimes, standing committees. A treaty without these becomes what the field calls a dead letter — formally in force and not operative.

Compliance research finds that regimes with monitoring and reporting persist; those without decay into nominal existence at a measurable rate.

The turn. A regime is a pattern of expectations maintained by continuous re-enactment, and the secretariat is its repair machinery.

Keohane's cost argument is a maintenance argument stated in the language of transaction costs.

Depth and form here. Form is which obligations and expectations. Depth is bilateral agreement, regime, order — each slower.

What follows. Regime collapse gains an ordering. When maintenance capacity falls, the deepest and most integrated arrangements fail first, while narrow bilateral ones persist. That is testable across historical breakdowns.

And withdrawal from a treaty stops being the main failure mode. The commoner one is a treaty in force whose re-enactment has stopped.

LVI. Public Administration and Policy Implementation

The accepted starting point. Policies do not implement themselves. Pressman and Wildavsky's study of a federal programme in Oakland showed how a straightforward policy with money attached and no visible opposition produced almost nothing, because implementation required a long chain of agreements each of which had to hold.

Where it stalls. The implementation gap is named and the field has no general account of its size.

What the field already measures. Pressman and Wildavsky's arithmetic is the finding. Multiply the probability that each link in a chain of clearance points holds, and the joint probability falls fast even when each link is likely. Their calculation is the field's most-cited insight and is rarely read as a maintenance statement.

Programme decay is also measured: initiatives that succeed under a project team and lapse when the team disbands.

The turn. A policy in effect is a pattern of connections between an intention and an outcome, maintained by continuous action at every link. The implementation gap is the difference between a pattern written down and a pattern being laid.

Depth and form here. Form is which links, in what arrangement. Depth is procedure, programme, agency, government, and reforms at the top routinely fail to reach the bottom because they change a slow layer while the fast layers go on as before.

What follows. Pilot projects that succeed and fail to scale gain an account. A pilot runs with a dedicated team supplying repair capacity that the scaled version does not have.

LVII. Migration and Diaspora Studies

The accepted starting point. Migration does not sever ties. Transnationalism research established that migrants sustain connections across borders as an ongoing condition rather than a transitional phase.

Where it stalls. Which ties persist across generations and which lapse is not predicted, only described.

What the field already measures. The maintenance is unusually visible and quantified. Remittances are recorded at national scale. Visits, calls, hometown associations and religious affiliations are all measured, and all are effortful and repeated.

And the decay is measured too: second and third generation ties weaken on a documented gradient unless specific institutions — language schools, associations, return visits — keep laying them.

The turn. A diaspora is a knot maintained across distance by costly repeated action, and remittance flows are its repair expenditure, recorded in national accounts.

Depth and form here. Form is which connections: family, village, region, nation, faith — and these decay at different rates, which is why the village tie often outlasts the national one.

Depth is household, hometown association, diaspora community, transnational field.

What follows. Assimilation and retention stop being a single axis. They are two patterns being laid at different rates, and both can rise at once.

And the generational gradient becomes computable from maintenance rates rather than described as inevitable drift.

LVIII. Sociolinguistics and Language Shift

The accepted starting point. Languages are lost, and the loss follows a recognisable sequence. Fishman's graded scale of disruption ranks the stages from a language used in all domains to one with no remaining speakers.

Where it stalls. Reversal efforts frequently target the wrong stage. Official status, signage and school provision often fail to arrest shift.

What the field already measures. Fishman's central finding is about which link matters. The critical stage is intergenerational transmission in the home. A language that has status, literature, schooling and broadcasting but is not spoken between parents and children continues to shift, and the scale is ordered accordingly.

The reason is that home transmission is the fastest, most frequent re-laying, and the others are slower layers that cannot substitute for it.

The turn. A language is a pattern maintained by use, and the domain that matters is the one where re-laying is most frequent. Slow layers cannot compensate for a lapsed fast layer, because they run at their own rate.

Depth and form here. Depth is exactly Fishman's scale, read as layers: home, neighbourhood, work, school, media, government, each slower than the last.

Form is which forms are maintained — which is why revived languages carry the pattern of the reviving generation.

What follows. Language policy gains a priority ordering derived rather than argued. Effort at a slow layer while the fast layer is lapsing produces documented decline with visible institutional activity, which is the commonest observed outcome.

LIX. Family Studies

The accepted starting point. Family routines and rituals predict child outcomes and family functioning. Fiese and colleagues' review of fifty years of research established the finding across health, academic and emotional measures.

Where it stalls. Why a shared meal or a bedtime routine should predict outcomes is explained by proxies: communication, monitoring, predictability.

What the field already measures. The measures that predict are frequency and regularity of repeated practices — meals taken together, bedtime routines, weekly observances, annual celebrations. Not attitudes, and not resources.

And the review distinguishes routine from ritual by meaning and continuity: routines are done and forgotten, rituals are remembered and expected, and it is the latter that predicts more strongly.

The turn. A family is a knot, and its routines are its maintenance schedule. The prediction works because frequency of re-laying is the quantity that determines whether a pattern holds.

Depth and form here. Depth is legible in the schedule itself: the daily meal maintains a fast layer, the weekly observance a slower one, the annual celebration the slowest. Each layer requires its own frequency, and the model says the ratios between them are ratios of whole numbers.

Form is which practices, in what arrangement — what makes this family this one.

What follows. Interventions gain a target. The variable is frequency of maintained practice at the appropriate layer, not quality of communication in the abstract.

And family dissolution gains an ordering: the deepest, least frequent observances go first, while daily routines persist longest.

LX. Care Ethics and Care Work

The accepted starting point. Care is work, it is continuous, and it is systematically undervalued because it produces no visible product.

Where it stalls. Economics has no place for an activity whose output is that nothing changed. Care work is measured by hours and by cost, and its product is unnameable in the categories available.

What the field already measures. Fisher and Tronto defined care as everything we do to maintain, continue and repair our world so that we can live in it as well as possible. That definition, written in

1990 for a feminist theory of caring, is the definition of the object in this book, arrived at from an entirely different concern.

Time-use data on care work exists in national statistics and shows what the definition implies: an enormous continuous expenditure whose output is the absence of decline.

The turn. Care is repair. Not repair as a metaphor for care, but care as the general operation by which any knot is maintained, performed at the level of persons and households.

This field named the object before any of the others, and defined it correctly.

Depth and form here. Depth is why care cannot be made efficient in the way production can. Each layer must be laid at its own rate, and a deep layer cannot be laid faster than it turns. Care that is compressed reaches only the shallowest layer.

Form is which relations are maintained.

What follows. The invisibility of care work gains a structural explanation rather than only an ideological one. Maintenance produces no change, and every accounting system in the disciplines of Part One measures change.

And the undervaluation is not a valuation error to be corrected by better metrics. It follows from measuring output as difference.

LXI. Accounting and Audit

The accepted starting point. An entity's accounts are prepared on the assumption that it will continue in operation. The going concern assumption underlies the whole apparatus, and abandoning it changes every valuation in the statements.

Where it stalls. Going concern is assessed by judgement, on evidence about the next twelve months. What continuing consists of is not defined.

What the field already measures. The whole discipline is a maintenance operation. Reconciliation, stocktaking, verification, confirmation, the audit cycle: each is a comparison between the recorded pattern and the actual one, followed by correction. The books do not stay right; they are made right, repeatedly.

Power's analysis of the audit society describes the expansion of this activity across institutions, and notes that audit produces comfort rather than product.

The turn. An entity is a maintained pattern, and its accounts are a periodic verification of that pattern. Going concern is the judgement that re-laying will continue.

Accounting has been performing the check for five centuries without naming what is checked.

Depth and form here. Form is the pattern of claims and obligations. Depth is transaction, account, entity, group, consolidated whole — each verified at its own cycle.

What follows. Going concern gains a criterion that is not a forecast of solvency. An entity continues while its maintenance gets round its pattern, which is a different question from whether it can pay next year.

And the finding that audit produces no product is exactly right and is not a criticism. Maintenance produces no product anywhere in this book.

LXII. Financial Market Microstructure

The accepted starting point. Liquidity is not a property that markets have. It is supplied, continuously, by participants who post quotes and stand ready to trade.

Where it stalls. Liquidity is measured by proxies — spread, depth, resilience — and the field is clear these are indicators of something that has no direct measure.

What the field already measures. Kyle's model formalises how a market maker sets prices under adverse selection, and the whole literature since studies the conditions under which quoting is worth doing.

The measurement that matters is what happens when it stops. In the flash crash of 2010, liquidity did not decline; it withdrew, and the order book emptied within minutes. The market did not become less liquid. It stopped being a market.

The turn. A market is a pattern of standing willingness to trade, maintained by continuous quoting, and it exists while that maintenance runs.

Liquidity is not a stock and not a fluid. It is a re-laying rate.

Depth and form here. Form is which willingness at which prices — the shape of the book. Depth is order, book, venue, market, financial system, and each is closed over the one below with its own timescale, from microseconds to years.

What follows. Liquidity crises stop being extreme cases of illiquidity and become a different phenomenon: the cessation of maintenance rather than its reduction. That is a threshold, and it explains the observed discontinuity.

And market structure regulation gains a criterion: does the design keep quoting worth doing at the moments when the pattern is under strain.

LXIII. Human Factors and Skill Currency

The accepted starting point. Skills decay without practice, and the decay is fast enough that safety-critical professions regulate for it. Aviation requires recent experience before carrying passengers; surgical, anaesthetic and emergency skills are subject to recertification.

Where it stalls. Currency intervals are set by convention and negotiation, and vary widely between jurisdictions for the same task.

What the field already measures. Arthur and colleagues' meta-analysis of skill decay established the pattern: decay increases with the length of the non-use interval, and is faster for cognitive than for physical tasks, faster for closed-loop than for open-loop, and faster for rarely practised procedures.

Simulator research measures the re-laying side directly, giving both rates for the same task.

The turn. A skill is a pattern maintained by practice, with a measurable half-life. Currency requirements are maintenance schedules, and the question of what interval to set is a question about a ratio.

Depth and form here. Depth explains the cognitive–physical difference. Physical skills sit deeper — laid more often over a longer history, closed over more layers — and therefore hold longer. Rarely practised emergency procedures sit shallowest and lapse first, which is exactly what the data show and why they are drilled.

Form is which procedures are maintained.

What follows. Currency intervals become computable from the decay data the field already has, rather than negotiated.

And this specialisation is one of the few in this book with both rates measured for the same pattern. Their ratio would be the first empirical repair-to-decay number for a human capability.

LXIV. Museology and Collections Management

The accepted starting point. A collection requires continuous care. Preventive conservation — control of environment, monitoring, handling protocol, pest management — is the discipline's central activity, and it is understood to be more important than intervention.

Where it stalls. Conservation theory has argued for a century over what is being preserved: the material, the appearance, the intention, or the function. Muñoz Viñas set out how far the material-truth position has eroded.

What the field already measures. Deterioration rates are quantified per material and per condition. Risk-based collection management estimates expected loss over time and allocates resources accordingly, which is an explicit repair-versus-decay calculation.

And the field measures the consequence of ceasing: collections without care do not stay as they are.

The turn. A collection is a pattern maintained by continuous intervention, and an object in it is a place where maintenance is happening.

Depth and form here. Form is which objects and relations constitute this collection. Depth is object, collection, institution, and the knowledge of how to care for the material — which is itself maintained by practice and lost when a specialism lapses.

What follows. The theoretical dispute gains a resolution by depth. Material, appearance and function are patterns at different depths, and a decision to preserve one at the expense of another is a decision about which layer to keep laying.

And the loss of conservation specialisms becomes the most serious form of collection loss, because it removes the repair capacity for everything below.

LXV. Cognitive Anthropology

The accepted starting point. People in a community share cognitive models — of illness, kinship, weather, success — and the models are neither individual idiosyncrasy nor formal doctrine.

Where it stalls. Where a cultural model resides is the field's version of the same problem. In heads, distributed across heads, or in the environment, and each answer has known difficulties.

What the field already measures. Consensus analysis measures agreement within a group and estimates both the shared model and individual competence in it. The measurements show that models are neither uniformly held nor arbitrarily variable: there is a centre of gravity that individuals approximate to varying degrees.

D'Andrade's and Shore's accounts both emphasise that models are sustained by repeated instantiation in ordinary practice rather than by explicit teaching.

The turn. A cultural model is a pattern re-laid across a population by ordinary practice, and the consensus that analysis detects is the class into which individuals keep laying it.

Nobody holds the model. It is what the laying converges on.

Depth and form here. Form is which model: what makes this one this one. Depth is schema, model, worldview, each slower to change.

What follows. The location question dissolves in the same way as it did for language, memory and law. The model is not stored anywhere; it is laid again, and what recurs is the class.

And cultural change gains a rate rather than a narrative: a model shifts when the laying shifts, at a speed set by how often it is laid.

Technical Appendix: From One Line to Two Numbers

Every quantitative statement in this book follows from the seven steps below, and nothing else is used.

A1. The setting

One continuous line. Where it touches itself, a contact. A closed loop held by contacts, a knot. One quantity spreads along the line and across contacts, always from more to less; call it flow.

Contacts across which nothing runs are not re-laid and lapse. New contacts are laid where flow runs.

Four quantities carry everything.

C — the number of contacts the pattern requires: the size of the form. λ — the rate at which an idle contact lapses. r — the rate at which a lapsed or misplaced contact is put back. $R \equiv r/\lambda$ — the repair-to-decay ratio, a pure number. f — the fraction of time in which nothing is running through, so that repair can run.

A2. Retention time

A knot holds what flows into it and exchanges at its open contacts. Write its capacity as the amount of line it contains and its openness as the sum of the conductances of its open contacts. The time it holds without input is

$$\tau = \text{capacity} / \text{openness}.$$

Large and barely open holds long; small and wide open holds briefly. This is the ordinary relation for any well-mixed compartment exchanging with its surroundings.

A3. What closing does — the tempo ratio

Take q constituent knots, each keeping b open contacts of comparable conductance. Their total openness is $q \cdot b$.

Closing lays new contacts running over the constituents as wholes. Each such contact uses one open contact on each of two constituents and turns both inward. Write ζ for the number of new contacts per constituent; the minimum that closes a ring over q constituents is one, so $\zeta \geq 1$. The openness taken inward is $2\zeta q$, and the fraction taken inward is

$$\phi = 2\zeta q / (q \cdot b) = 2\zeta / b.$$

Capacity is unchanged by closing: it is the sum of the constituents'. So by A2 the new retention time is the old one divided by what remains open, and the ratio between adjacent depths is

$$\sigma = 1/(1 - \phi) = b / (b - 2\zeta).$$

Two readings follow. Any real closure has $\phi > 0$ and therefore $\sigma > 1$: a knot of knots always holds longer than its parts, which is not an assumption but a count of contacts. And $2\zeta < b$ is required — a living knot keeps part of its boundary open, since $\phi = 1$ means nothing open, nothing running through, and by A1 nothing re-laid.

Because b and ζ are whole numbers, σ is a ratio of whole numbers. A measured tempo ratio between adjacent depths therefore determines b and ζ , and those must agree with an independent count of open connections. This is what the statements about tempo ratios in Chapters XXII, XXX, LIX and LXIII rest on.

A4. The upper bound on form

Re-laying follows the local gradient, so some replacement contacts land beside the pattern rather than in it. The chance of landing correctly falls as the pattern grows, since a larger pattern has shorter intervals between its contacts: write the hit probability as $C^a(-a)$, with a equal to 1 or 2.

Let μ be the number of contacts re-laid per unit of flow. Contacts are then laid at rate μJ , of which a fraction $(1 - C^a(-a))$ lands outside the pattern; repair returns them at rate r while contacts lapse at rate λ . A pattern is maintainable when repair outpaces the loss it must cover:

$$\mu r > \lambda \cdot \mu(1 - C^a(-a)) \cdot C.$$

μ cancels on both sides. With $R = r/\lambda$ this gives $R > C - C^a(1-a)$, and to leading order

$$C \leq R.$$

The largest form a knot can hold equals its repair-to-decay ratio. How fast it re-lays does not enter; only the ratio does. This is the bound used in Chapters XXVI, XXXI, XXXII, XLIII, XLIV, XLVIII and LIII.

A5. The required rest fraction

Repair runs only where flow is near zero. Let x be the ratio of drift rate to repair rate. The stationary fraction of time spent in repair phases is $f = x/(1+x)$, and the stationary number of maintained contacts works out to

$$C^* = R \cdot f.$$

Maintenance requires $C^* \geq C$, hence $f \geq C / R$.

Required rest is the size of the form divided by the repair-to-decay ratio. No load term appears: the required fraction is independent of effort. The achieved fraction is not, since it depends on whether flow actually reaches zero — which is why a knot prevented from reaching zero falls below its requirement however light the load. This is what Chapters X, XXXI, XXXV, LX and LXIII rest on.

A6. Depth is bounded

Each closing gathers q constituents and ties them with ζq new contacts, so the new form contains the constituent forms plus the ties:

$$C(k+1) = q \cdot C(k) + \zeta q.$$

Solving, with $B = \zeta q/(q-1)$ and $A = C(0) + B$:

$$C(k) = A \cdot q^k - B.$$

Form grows geometrically with depth. The bound of A4 does not move. So depth terminates at the last level whose form still fits under $C \leq R \cdot f$: $m = \lfloor \log((R \cdot f + B)/A) / \log q \rfloor$.

Because depth depends on R only through a logarithm, a thousandfold increase in repair capacity buys a handful of further levels rather than a thousand. Towers are short. This is what the statements about finite depth in Chapters XXXVII and XLII, and about failure ordering in Chapters XLVI and LV, rest on.

A7. The two numbers as combinatorics

Lay the contacts of a knot out along the line. Two contacts stand in one of two relations. They cross when their endpoints alternate along the line. They nest when one lies wholly inside the other.

Form is the crossing structure. Depth is the nesting structure — the length of the longest chain of contacts each lying inside the previous, which is exactly what repeated closing builds.

These are the two standard statistics of a chord diagram. Chen, Deng, Du, Stanley and Yan proved that their joint distribution is symmetric, so form and depth stand on equal mathematical footing. Crossings, not nestings, give the associated surface its handles; a diagram whose contacts only nest lies flat. The two statistics do different geometric work.

Annotated References

Part One — the human and social sciences

Sociology

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Latour, B. (2005). Reassembling the Social. Oxford University Press. Groups exist only while being performed. *Why read?* For the performance argument, and to see what a flat ontology costs: without depth, a person and an institution must be actors in the same plane.

Kinship

Schneider, D. (1984). A Critique of the Study of Kinship. University of Michigan Press. *Why read?* The demolition of the genealogical grid; the reason the field needed a new object.

Carsten, J. (ed.) (2000). Cultures of Relatedness. Cambridge University Press. Kinship as made and maintained. *Why read?* The field's own account of relatedness as something continually fed. Read the introduction; it is the knot without the count.

Linguistics

Bybee, J. (2006). From usage to grammar: the mind's response to repetition. *Language* 82(4), 711–733. *Why read?* Entrenchment and decay as functions of frequency; the maintenance mechanism of a language, measured.

Hopper, P. (1987). Emergent Grammar. *Berkeley Linguistics Society* 13, 139–157. *Why read?* Grammar as a running deposit of use rather than a prior system. Short and direct.

Conversation analysis

Sacks, H., Schegloff, E. & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language* 50(4), 696–735. *Why read?* The founding paper; local production of order.

Schegloff, E., Jefferson, G. & Sacks, H. (1977). The preference for self-correction in the organization of repair in conversation. *Language* 53(2), 361–382. *Why read?* This field named repair and demonstrated that interaction runs on it. Note the preference for self-repair, which follows structurally from the fact that repair from inside a closure does not cross a boundary.

Oral tradition

Lord, A.B. (1960). The Singer of Tales. Harvard University Press. *Why read?* The single cleanest documented case of a pattern re-laid in new material at every performance and remaining the same. Read the chapters on the singer's own account of singing it "the same way".

Psychology

Roberts, B.W. & DelVecchio, W.F. (2000). The rank-order consistency of personality traits from childhood to old age. *Psychological Bulletin* 126(1), 3–25. *Why read?* The stability finding on which the chapter rests.

Thelen, E. & Smith, L.B. (1994). A Dynamic Systems Approach to the Development of Cognition and Action. MIT Press. Soft assembly. *Why read?* Stable behaviour assembled in the moment rather than retrieved. The nearest thing to the model in developmental psychology, missing only depth.

Safran, J.D. & Muran, J.C. (2000). Negotiating the Therapeutic Alliance: A Relational Treatment Guide. Guilford. Rupture and repair. *Why read?* Repaired ruptures predict better outcomes than the absence of rupture — the strongest clinical evidence that repair capacity, not damage, is the variable.

Tronick, E. (2007). The Neurobehavioral and Social-Emotional Development of Infants and Children. Norton. The still-face paradigm and mismatch-repair cycles. *Why read?* The same finding at the beginning of life.

Aron, A., Aron, E.N. & Smollan, D. (1992). Inclusion of Other in the Self Scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology* 63(4), 596–

612. *Why read?* Seven pairs of circles measuring shared boundary. Note that it is taken once; the model concerns its course over time.

Baader, M., Starmer, C., Tufano, F. & Gächter, S. (2024). Introducing IOS11 as an extended interactive version of the 'Inclusion of Other in the Self' scale. *Scientific Reports* 14, 8901. *Why read?* The instrument that allows repeated, finer capture.

Economics and organisations

Coase, R. (1937). The Nature of the Firm. *Economica* 4(16), 386–405. *Why read?* The question that has never been closed, and the reason the boundary of a firm is a live problem.

Nelson, R. & Winter, S. (1982). An Evolutionary Theory of Economic Change. Harvard University Press. Routines as organisational memory, remembered by being exercised. *Why read?* The re-laying claim, stated plainly in economics in 1982.

Ostrom, E. (1990). Governing the Commons. Cambridge University Press. Design principles for durable institutions, including monitoring and graduated sanctions. *Why read?* Read the design principles as a specification of repair capacity, which is what makes them predictive.

North, D. (1990). Institutions, Institutional Change and Economic Performance. Cambridge University Press. *Why read?* The distinction between formal rules and informal constraints, and the observation that the slow ones dominate — retention time under another name.

Weick, K. & Roberts, K. (1993). Collective mind in organizations: heedful interrelating on flight decks. *Administrative Science Quarterly* 38(3), 357–381. *Why read?* Collective mind existing only in ongoing activity, observed under conditions where failure is immediate and visible.

Feldman, M. & Pentland, B. (2003). Reconceptualizing organizational routines as a source of flexibility and change. *Administrative Science Quarterly* 48(1), 94–118. *Why read?* The ostensive and performative aspects; the routine existing in its performances.

State, law, archaeology

Tilly, C. (1990). Coercion, Capital, and European States. Blackwell. *Why read?* For the machinery of state formation read as maintenance apparatus: census, registry, court, survey.

Scott, J.C. (1998). Seeing Like a State. Yale University Press. Legibility as a continuous achievement against drift. *Why read?* The same apparatus from the other side, with the drift made explicit.

Maitland, F.W. (1900). Moral Personality and Legal Personality. *Journal of the Society of Comparative Legislation* 3, 192–200. *Why read?* The clearest statement of the corporate personality problem by the person best placed to solve it, and his reasons for not doing so. Short.

Hodder, I. (2012). Entangled: An Archaeology of the Relationships between Humans and Things. Wiley-Blackwell. Things require continual care, and care creates dependence. *Why read?* The maintenance burden of material culture, argued with excavated evidence.

Demography, infrastructure, memory, ritual, music, learning, archives

Lotka, A.J. (1939). Théorie analytique des associations biologiques, part II. Hermann. Stable population theory. *Why read?* A population maintained by replacement, with the mathematics complete. The renewal equation is available to any field in this book that lacks equations.

Star, S.L. (1999). The Ethnography of Infrastructure. *American Behavioral Scientist* 43(3), 377–391. *Why read?* Infrastructure invisible until it breaks; its normal state is repair.

Graham, S. & Thrift, N. (2007). Out of Order: Understanding Repair and Maintenance. *Theory, Culture & Society* 24(3), 1–25. *Why read?* The founding statement of maintenance and repair studies — a whole specialisation whose subject is re-laying.

Assmann, J. (1992). Das kulturelle Gedächtnis. C.H. Beck. Communicative memory reaching roughly eighty years; cultural memory carried by institutions of repetition. *Why read?* A decay curve with a maintenance threshold, established comparatively.

Rappaport, R. (1999). Ritual and Religion in the Making of Humanity. Cambridge University Press. Liturgical orders invariant while performers change. *Why read?* Ritual as the maintenance operation of a deep knot.

Whitehouse, H. (2004). Modes of Religiosity. AltaMira. The frequency–intensity trade-off. *Why read?* Two re-laying schedules, found empirically; the model makes them two depths of one operation.

Clayton, M., Sager, R. & Will, U. (2005). In time with the music: the concept of entrainment and its significance for ethnomusicology. *European Meetings in Ethnomusicology* 11, 3–142. *Why read?* The best-developed treatment of phase coupling in the human sciences. Entrainment is a phase relation, not an amplitude one — the point on which the whole coupling question turns.

Cepeda, N.J., Pashler, H., Vul, E., Wixted, J.T. & Rohrer, D. (2006). Distributed practice in verbal recall tasks: a review and quantitative synthesis. *Psychological Bulletin* 132(3), 354–

380. *Why read?* The spacing effect with the scaling: optimal gap rises with required retention. A maintenance schedule with a rate.

Ebbinghaus, H. (1885). Über das Gedächtnis. Duncker & Humblot. *Why read?* The original decay measurement, and still the clearest.

Rothenberg, J. (1995). Ensuring the Longevity of Digital Documents. *Scientific American* 272(1), 42–47. *Why read?* Digital material persisting only as long as the process that keeps migrating it. The article that reframed preservation as continuous action.

Part Two — the life, medical and formal sciences

Biochemistry and genetics

Schoenheimer, R. (1942). The Dynamic State of Body Constituents. Harvard University Press. *Why read?* The isotope work establishing continuous replacement. Short, and still the clearest presentation of the fact this whole book takes as its definition.

Balch, W.E., Morimoto, R.I., Dillin, A. & Kelly, J.W. (2008). Adapting proteostasis for disease intervention. *Science* 319(5865), 916–919. *Why read?* Proteostasis as the maintenance network, framed as a therapeutic target. The field's own word for the object.

Eigen, M. (1971). Selforganization of matter and the evolution of biological macromolecules. *Naturwissenschaften* 58(10), 465–523. *Why read?* The error threshold. This is the model's central inequality, established fifty-five years ago by an independent route, with numbers.

Orgel, L.E. (1963). The maintenance of the accuracy of protein synthesis and its relevance to ageing. *PNAS* 49(4), 517–521. *Why read?* The same inequality read toward failure, and applied to ageing.

Belshaw, R., Gardner, A., Rambaut, A. & Pybus, O.G. (2008). Pacing a small cage: mutation and RNA viruses. *Trends in Ecology & Evolution* 23(4), 188–193. *Why read?* The RNA virus figures — roughly 10^4 bases at 10^{-4} errors per base — together with a critical discussion of whether the error threshold is the right explanation for them. Read it for the objection as much as the numbers.

Kunkel, T.A. (2004). DNA replication fidelity. *Journal of Biological Chemistry* 279(17), 16895–

16898. *Why read?* How the 10^9 – 10^{10} figure is assembled from selectivity, proofreading and mismatch repair — three nested layers, each multiplying the bound.

Cell biology and immunology

Maturana, H. & Varela, F. (1980). Autopoiesis and Cognition. Reidel. *Why read?* The most developed self-maintenance theory in biology, and the nearest neighbour to this book. Note that autopoiesis is a category rather than a quantity, which is why its extension to other levels has to be declared rather than counted.

Luisi, P.L. (2003). Autopoiesis: a review and a reappraisal. *Naturwissenschaften* 90(2), 49–59. *Why read?* The chemical operationalisation, and an honest account of what the concept can and cannot carry.

Jerne, N.K. (1974). Towards a network theory of the immune system. *Annales d'Immunologie* 125C, 373–389. *Why read?* Immune self as a network state rather than a list. The formalism did not survive; the observation did.

Matzinger, P. (1994). Tolerance, danger, and the extended family. *Annual Review of Immunology* 12, 991–1045. *Why read?* For the failures of the self–non-self frame, set out by the person who did most to break it.

Gilbert, S.F., Sapp, J. & Tauber, A.I. (2012). A symbiotic view of life: we have never been individuals. *Quarterly Review of Biology* 87(4), 325–341. *Why read?* The boundary problem stated at its sharpest. The model's answer is that the boundary is where connections are open, and that both the human and the holobiont are knots at their own depths.

Neuroscience

Crick, F. (1984). Memory and molecular turnover. *Nature* 312, 101. *Why read?* One page. The problem posed with complete clarity forty years ago.

Rule, M.E., O'Leary, T. & Harvey, C.D. (2019). Causes and consequences of representational drift. *Current Opinion in Neurobiology* 58, 141–147. *Why read?* The population code changing while behaviour is stable. This is re-laying, measured, under the field's own name.

Hasson, U., Yang, E., Vallines, I., Heeger, D.J. & Rubin, N. (2008). A hierarchy of temporal receptive windows in human cortex. *Journal of Neuroscience* 28(10), 2539–2550. *Why read?*

Nested timescales, ordered by level, measured. The ratios between adjacent windows are the model's tempo ratios, and the data to check them exist.

Medicine, ageing, rehabilitation, epidemiology, psychiatry

Kirkwood, T.B.L. (1977). Evolution of ageing. *Nature* 270, 301–304. *Why read?* The disposable soma theory: ageing as under-investment in maintenance. The model's inequality, in evolutionary form, in three pages.

Fried, L.P. et al. (2001). Frailty in older adults: evidence for a phenotype. *Journal of Gerontology A* 56(3), M146–M156. *Why read?* Frailty indices count maintained functions and their loss. The instrument for testing whether loss proceeds from the deepest layer down.

Saltin, B. et al. (1968). Response to exercise after bed rest and after training. *Circulation* 38(5 Suppl), VII1–78. *Why read?* The Dallas bed rest study. The cleanest decay measurement in medicine, and half of the ratio nobody has computed.

McEwen, B.S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine* 338(3), 171–179. *Why read?* Allostatic load as accumulated maintenance cost. Read it with the question of what is being maintained and at what rate.

Borsboom, D. (2017). A network theory of mental disorders. *World Psychiatry* 16(1), 5–13. *Why read?* Disorders as self-sustaining symptom networks rather than effects of hidden entities. The knot in psychiatry, on one plane; depth is what it is missing.

Anderson, R.M. & May, R.M. (1991). *Infectious Diseases of Humans*. Oxford University Press. *Why read?* The best-developed mathematics of re-laying in the life sciences: reproduction numbers, thresholds, susceptible replenishment. Available to any chapter in this book that lacks equations.

Ecology and evolution

Odum, E.P. (1969). The strategy of ecosystem development. *Science* 164(3877), 262–270. *Why read?* Structure maintained by throughflow, stated as a general principle for ecosystems.

Ulanowicz, R.E. (1986). *Growth and Development: Ecosystems Phenomenology*. Springer. *Why read?* The flow pattern rather than the species inventory as the object. Form, in ecology.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4, 1–23. *Why read?* Resilience distinguished from stability — the capacity to reorganise, which is repair capacity under another name.

Maynard Smith, J. & Szathmáry, E. (1995). *The Major Transitions in Evolution*. W.H. Freeman. *Why read?* Each transition is one closure, and the list is short. Read it as a count of depth, and ask why the list ends where it does.

Turing, A.M. (1952). The chemical basis of morphogenesis. *Philosophical Transactions of the Royal Society B* 237(641), 37–72. *Why read?* Pattern from local interaction without a plan. The founding demonstration that form needs no blueprint.

Formal sciences

Bar-Natan, D. (1995). On the Vassiliev knot invariants. *Topology* 34(2), 423–472. *Why read?* Chord diagrams as the algebra underlying finite-type invariants — the existing mathematics of the alphabet of forms.

Thomson, W. (Lord Kelvin) (1867). On Vortex Atoms. *Proceedings of the Royal Society of Edinburgh* 6, 94–105. *Why read?* Matter as knotted motion in a medium. The oldest statement, and short.

Faddeev, L. & Niemi, A. (1997). Stable knot-like structures in classical field theory. *Nature* 387, 58–61. *Why read?* Knotted configurations with a conserved topological charge — form as a discrete, countable label in physics.

Prigogine, I. & Nicolis, G. (1977). *Self-Organization in Nonequilibrium Systems*. Wiley. *Why read?* Dissipative structures: order that exists only while flow runs. The maintenance half of the physics, without the identity invariant.

Dijkstra, E.W. (1974). Self-stabilizing systems in spite of distributed control. *Communications of the ACM* 17(11), 643–644. *Why read?* Two pages. A system that converges to a legitimate state from any state, without external intervention — re-laying as an engineering requirement, with proofs.

Shannon, C.E. (1948). A mathematical theory of communication. *Bell System Technical Journal* 27, 379–423 and 623–656. *Why read?* Reliable retention over an unreliable medium, with a bound set by the ratio of correction to corruption. The general proof of the inequality that governs every chapter in this book.

Ashby, W.R. (1956). *An Introduction to Cybernetics*. Chapman & Hall. *Why read?* Requisite variety. The model adds a second requirement the law does not contain: the regulator must also get round its own pattern.

Simon, H.A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society* 106(6), 467–482. *Why read?* Near-decomposability and the assembly advantage of hierarchy, derived rather than asserted. The consequence of closure, described before the operation was named.

Beer, S. (1979). *The Heart of Enterprise*. Wiley. *Why read?* The viable system model and its recursion: each viable system contains and is contained in viable systems of the same form. Depth, without a bound.

Part Three — the applied and technical disciplines

Cultural transmission

Boyd, R. & Richerson, P.J. (1985). *Culture and the Evolutionary Process*. University of Chicago Press. *Why read?* The formal apparatus for culture as a second inheritance system with its own transmission dynamics.

Henrich, J. (2004). Demography and cultural evolution: how adaptive cultural processes can produce maladaptive losses — the Tasmanian case. *American Antiquity* 69(2), 197–214. *Why read?* A documented loss of accumulated complexity through insufficient transmission, with a model. This is the error threshold in anthropology, and neither field cites the other.

Sperber, D. (1996). Explaining Culture: A Naturalistic Approach. Blackwell. *Why read?* Representations persisting as a function of reproduction fidelity rather than truth. The epidemiological framing, before the epidemiology chapter.

Criminology and movements

Hirschi, T. (1969). Causes of Delinquency. University of California Press. *Why read?* Bonds as the unit, and offending as what happens when they weaken.

Sampson, R.J. & Laub, J.H. (2003). Shared Beginnings, Divergent Lives. Harvard University Press. *Why read?* The Glueck cohort followed to old age. Note the finding that a bond predicts desistance only when it is invested in — the maintenance, not the status.

Taylor, V. (1989). Social Movement Continuity: The Women's Movement in Abeyance. *American Sociological Review* 54(5), 761–775. *Why read?* Abeyance structures: continuity achieved by a reduced structure doing continuous maintenance. The general behaviour of any knot under falling capacity, observed in one case.

Organisations, texts, heritage

Hannan, M.T. & Freeman, J. (1984). Structural Inertia and Organizational Change. *American Sociological Review* 49(2), 149–164. *Why read?* Reproducibility is what makes an organisation reliable and what makes it hard to change. Read those as one quantity rather than a trade-off.

Stinchcombe, A. (1965). Social Structure and Organizations. In J.G. March (ed.), *Handbook of Organizations*. Rand McNally. *Why read?* The liability of newness — a pattern being laid for the first time has nothing to fall back into.

Maas, P. (1958). Textual Criticism. Oxford University Press. *Why read?* The method in its most compressed form. Short. Read it as a study of a re-laying process with measured error rates.

Muñoz Viñas, S. (2005). Contemporary Theory of Conservation. Elsevier. *Why read?* How far the material-truth position in conservation has eroded, and what replaced it.

ICOMOS (1994). The Nara Document on Authenticity. *Why read?* Two pages. International doctrine establishing that authenticity is not material originality, written because cases like Ise could not be described otherwise.

Cooperation, health, standards

Axelrod, R. (1984). The Evolution of Cooperation. Basic Books. *Why read?* The shadow of the future as the decisive parameter — the re-laying rate, proved rather than observed.

Berkman, L.F. & Syme, S.L. (1979). Social networks, host resistance, and mortality: a nine-year follow-up study of Alameda County residents. *American Journal of Epidemiology* 109(2), 186–204. *Why read?* The founding result. Note that what predicts is ties actively maintained, not ties nominally present.

Holt-Lunstad, J., Smith, T.B. & Layton, J.B. (2010). Social relationships and mortality risk: a meta-analytic review. *PLoS Medicine* 7(7), e1000316. *Why read?* For the size of the effect, which no proposed mechanism accounts for.

O'Connell, J. (1993). Metrology: The Creation of Universality by the Circulation of Particulars. *Social Studies of Science* 23(1), 129–173. *Why read?* Universality as an achievement of continuous circulation and comparison. A calibration chain is a re-laying chain, and this is the best study of one.

Latour, B. (1987). *Science in Action*. Harvard University Press. *Why read?* For the metrological chains argument specifically; the rest is background here.

Commerce, military, treaties, administration

Ehrenberg, A.S.C. (1988). Repeat-Buying: Facts, Theory and Applications. Griffin. *Why read?* Purchase patterns as stable and predictable, depending on continued presence rather than persuasion.

Shils, E. & Janowitz, M. (1948). Cohesion and Disintegration in the Wehrmacht in World War II. *Public Opinion Quarterly* 12(2), 280–315. *Why read?* Combat motivation tracking the primary group. Read it alongside the replacement-policy literature: the finding about individual replacements into an existing formation is the maintenance argument in its clearest empirical form.

Keohane, R. (1984). *After Hegemony*. Princeton University Press. *Why read?* Regimes persisting because maintenance costs less than replacement. A maintenance argument in the language of transaction costs.

Pressman, J. & Wildavsky, A. (1973). *Implementation*. University of California Press. *Why read?* The clearance-point arithmetic. The most-cited insight in the field, and rarely read as a statement about how many links must hold simultaneously.

Power, M. (1997). *The Audit Society*. Oxford University Press. *Why read?* Audit as an activity producing comfort rather than product. That is what maintenance does everywhere in this book, and it is not a criticism.

Migration, language, family, care

Levitt, P. (2001). *The Transnational Villagers*. University of California Press. *Why read?* Ties sustained across borders as an ongoing condition, with the costly repeated action made visible.

Fishman, J. (1991). Reversing Language Shift. *Multilingual Matters*. *Why read?* The graded scale, and the finding that intergenerational home transmission is the stage that decides. That is the fastest layer, and slow layers cannot substitute for it.

Fiese, B.H. et al. (2002). A review of 50 years of research on naturally occurring family routines and rituals. *Journal of Family Psychology* 16(4), 381–390. *Why read?* Frequency and regularity of repeated practice as the predictor. A maintenance schedule with outcomes attached.

Fisher, B. & Tronto, J. (1990). Toward a Feminist Theory of Caring. In E. Abel & M. Nelson (eds.), *Circles of Care*. SUNY Press. *Why read?* Care defined as everything we do to maintain, continue and repair our world. This is the definition of the object in this book, written in 1990 from an entirely different concern, and it is the earliest correct statement of it in the human sciences.

Tronto, J. (1993). *Moral Boundaries*. Routledge. *Why read?* The developed argument, and the account of why maintenance is invisible to systems that measure change.

Finance, skill, collections, cognition

Kyle, A.S. (1985). Continuous Auctions and Insider Trading. *Econometrica* 53(6), 1315–1335. *Why read?* The formal core of market microstructure. Liquidity as something supplied under conditions, not a property a market has.

O'Hara, M. (1995). Market Microstructure Theory. Blackwell. *Why read?* The standard treatment. Read it with the flash crash in view: liquidity did not decline, it withdrew.

Arthur, W., Bennett, W., Stanush, P.L. & McNelly, T.L. (1998). Factors that influence skill decay and retention: a quantitative review and analysis. *Human Performance* 11(1), 57–101. *Why read?* Decay by task type and non-use interval, quantified. One of the few places in this book where both rates exist for the same pattern; their ratio has not been taken.

D'Andrade, R. (1995). The Development of Cognitive Anthropology. Cambridge University Press. *Why read?* Cultural models sustained by repeated instantiation in ordinary practice rather than by teaching.

Shore, B. (1996). Culture in Mind. Oxford University Press. *Why read?* The fullest treatment of how models are carried, and of why the location question is the wrong question.

The object itself

Chen, W.Y.C., Deng, E.Y.P., Du, R.R.X., Stanley, R.P. & Yan, C.H. (2007). Crossings and nestings of matchings and partitions. *Transactions of the American Mathematical Society* 359(4), 1555–1575. *Why read?* The two statistics of a chord diagram and their symmetric joint distribution. Form and depth on equal mathematical footing.

Ingold, T. (2015). The Life of Lines. Routledge. *Why read?* The closest existing statement of the whole object, from social anthropology, without the counting.

Konstapel, J. & Claude (2026). The Human as Knot. constable.blog. *Why read?* The derivation of form and depth from a single continuous line, which this book applies without rederiving.

Konstapel, J. (2026). The Vacuum.Net Theory: Foundational Paper. constable.blog. *Why read?* For the origin. No chapter here depends on it.