

SMONAD · LEARNING SERIES

One source. Twelve lessons.

A course handbook for the Single Monad Model and the Duality of Time Theory

Source and memory · geometry and phase
clocks and symmetry · matter and constants

12 complete lessons · 12 diagrams
24 exercises · 24 worked answers

English course edition | 16 October 2026

Prepared from the website's complete lesson sequence. Read the lessons in order, solve the exercises before checking the answer section, and follow the linked guides for longer proofs.

Scope: This handbook distinguishes premises, conditional mathematical results, published results and physical identifications. It does not announce a derivation of the measured fine-structure constant or experimental confirmation of the complete SMM/DTT programme.

Contents

How to use this handbook	3
Lesson 01: One source, many distinguishable records	4
Lesson 02: Inner work and the completed record	8
Lesson 03: When two records predict the same future	12
Lesson 04: From six nested channels to three coordinates	16
Lesson 05: Build distance and test local influence	21
Lesson 06: Recover a complex phase from real rotation	25
Lesson 07: Quantum states, completion flags and memory	30
Lesson 08: Calibrated clocks and relativistic duration	34
Lesson 09: Local frames and observable loop comparisons	39
Lesson 10: Binding, hydrogen and the meaning of speed	44
Lesson 11: What 137 counts and what fixes a coupling	48
Lesson 12: Decide what a source model predicts	52
Worked answers	57
Further reading and publication record	61

How to use this handbook

An ordered path through the research programme

Lessons 1-3 | Source, time and records

Define the generating process, distinguish internal work from completed outcomes, and test whether two histories are predictively equivalent.

Lessons 4-6 | Geometry and phase

Calculate paired spatial ranks and binary refinement, then learn which additional structures select complex phase.

Lessons 7-9 | Quantum records, clocks and symmetry

Work with normalized states, physical clock comparisons and local frame transformations.

Lessons 10-12 | Matter, constants and evaluation

Study the Coulomb model, separate the count 137 from normalized response, and build an auditable claim ledger.

Reading and practice

Each lesson retains its learning objectives, prerequisites, examples, displayed equations, explanatory diagram, two exercises, scope statement and further reading. Worked answers are collected at the end so that the question can be attempted first. The original web course also offers expandable answers and links to interactive demonstrations.

What the labels mean

A premise is an input. An exact result follows within declared assumptions. A published mathematical result has a specific theorem scope. A physical identification requires an operational dictionary and empirical comparison. Similar symbols, integer counts or numerical agreement do not supply that bridge by themselves.

Online course and companion material

English course - <https://www.smonad.com/learn/index.html>

Arabic course - <https://www.smonad.com/arabic/course.html>

Worked derivations - <https://www.smonad.com/derivations/index.html>

Figure catalogue - <https://www.smonad.com/gallery/index.html>

Research claim map - <https://www.smonad.com/research/claims.html>

The package contains these pages. Newly added Expansion 06 URLs become available on the public site after its owner uploads the update.

Lesson 01: One source, many distinguishable records

How can one generating process support many different things? Begin with operations and records before assigning space, clocks or particles to them.

<https://www.smonad.com/learn/01-source-and-records.html>

The central connection

Unity counts sources; multiplicity counts distinguishable outcomes. A model connects them through explicit state, update, memory and readout rules.

What you will learn

- Distinguish a source from its states and histories.
- Count histories and identify which differences a detector retains.
- Write the ingredients of a minimal source model.

Before you begin: None. Familiarity with counting and the meaning of a rule is sufficient.

What does one source mean?

The Single Monad Model, abbreviated SMM, proposes a common generative origin for observable multiplicity. Start by separating two questions: how many sources are fundamental, and how many distinguishable results their activity can produce. A single musician can perform many sequences; the number of performers does not count the possible sequences. This analogy clarifies the logical distinction without supplying a physical explanation of the universe.

The proposed source is pre-spatial in the explanatory sense. Calling it a tiny point already presupposes a surrounding space, distance and position. A constructive account instead begins with allowed states and operations, then asks whether relationships among their outcomes can acquire spatial meaning. Nothing in this first step assigns a location to the source.

Keep four objects separate

A **state** contains the information used by a model to determine its next permitted changes. An **operation** changes that state. A **history** lists operations or states over an episode. A **record** is information retained when that episode finishes. An observation can reveal only part of the record, just as a counter display reveals less than all the circuitry maintaining it.

These distinctions prevent a common counting error. Many histories may end with the same displayed value, and one history may leave several correlated records. Neither number is automatically the number of active sources. The relevant physical question is how the declared mechanism creates, preserves and reads those distinctions. Memory therefore belongs among the resources of the model.

Worked example: eight histories, two labels

Suppose one source performs three successive operations, each labelled A or B. Assume every sequence is allowed. The histories are AAA, AAB, ABA, ABB, BAA, BAB, BBA and BBB: two choices at each of three positions give $2^3=8$ possibilities. Now let completion retain only whether the number of B operations is even or odd.

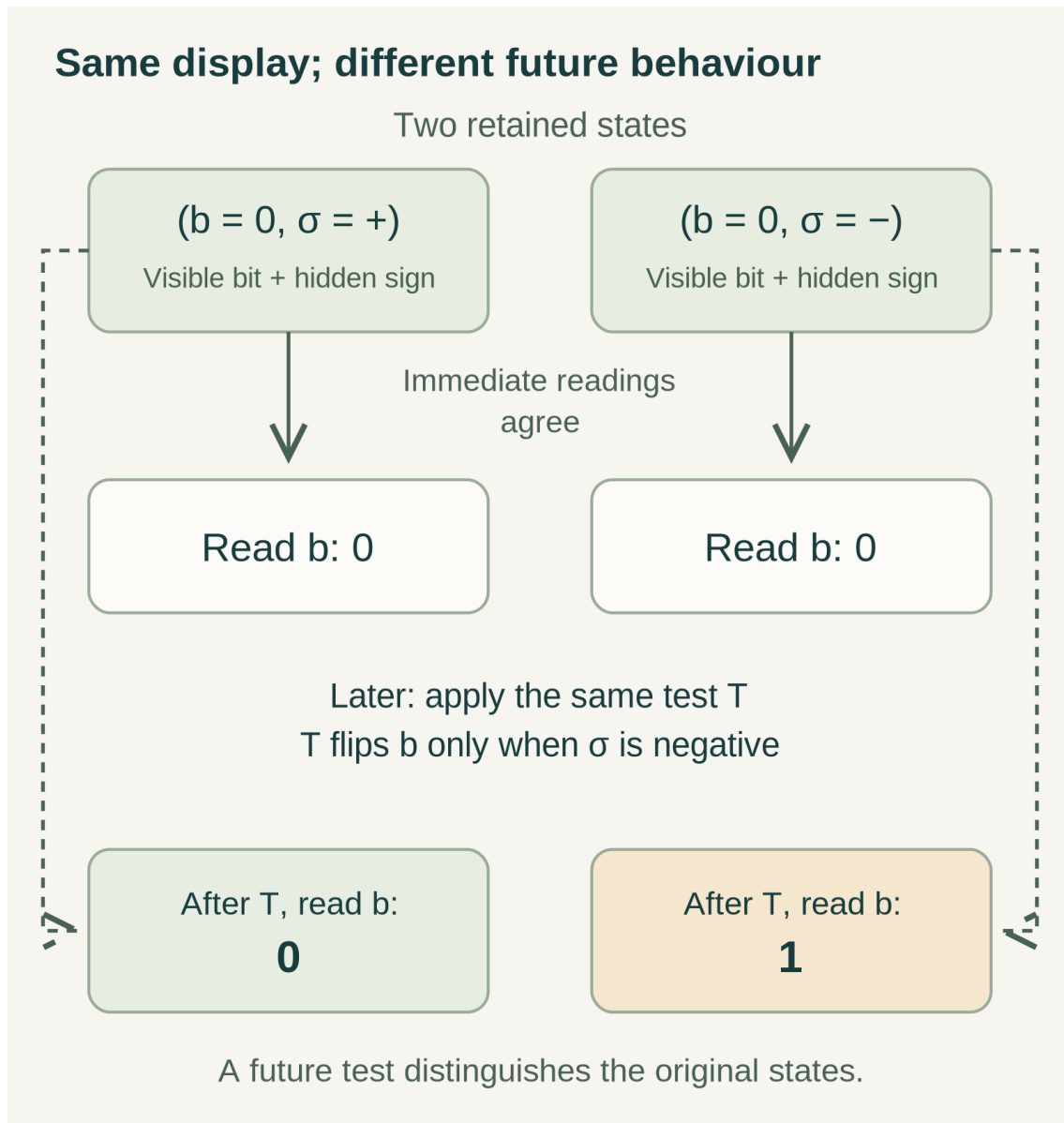
The even class contains AAA, ABB, BAB and BBA. The odd class contains AAB, ABA, BAA and BBB. Thus one source supports eight histories but only two parity records. If each history is prepared with probability $1/8$, each record has probability $4/8=1/2$. Equal probabilities follow from the specified preparation and count; a different preparation can make the two records unequal without changing the available labels.

Writing the connection as a map

A map is a rule that assigns an output to each allowed input. Write C for completion and O for observation. Their composite $\Pi=O\circ C$ means first complete the history, then inspect its retained result. In the parity example, Π sends a three-letter history to one bit, zero for even parity and one for odd parity.

$$\Pi(h)=O(C(h)); \quad h \text{ and } k \text{ have the same present observation when } \Pi(h)=\Pi(k).$$

This notation makes information loss visible. The map has eight possible inputs and two outputs. Reading parity cannot recover the whole sequence. That is a precise statement about this detector, not a claim that the unused history never existed or can never matter. A later operation may expose a distinction which the present detector ignores.



Conceptual illustration with an exact finite hidden-sign example. The same display value need not imply the same predictive state. An allowed future test separates histories that an immediate bit detector cannot distinguish. Open the full-size diagram →

From a premise to a model

To make a source proposal calculable, specify the complete state z and an update rule U , written $z_{n+1} = U(z_n)$. State which preparations are possible, which memory persists, how completion is certified and what a detector can read. The integer n counts applications of U ; it becomes a physical duration only after a clock has been defined and calibrated.

Compare two implementations of the parity recorder. One stores the full sequence and computes parity at the end. Another flips a single memory bit whenever B occurs. They agree for the present parity task but use different memory resources. A later request to recover the first letter separates them. An explanation must therefore name both its target observations and the operations it admits.

The question carried into the next lesson

DTT, the Duality of Time Theory, develops a distinction between inner generation and outer completion. The parity construction already supplies a modest example: several internal updates prepare one available result. The next lesson makes this dependency explicit without treating every internal stage as a separate measurable clock.

During the course, keep a small ledger with columns for assumptions, calculated outputs and physical interpretations. Here the two available operations, three-step episode and parity detector are assumptions; eight histories and two labels are outputs. Interpreting such records as matter or spatial events remains a further task. The [expanded SMM guide](#) develops this programme, including persistence and the need to derive useful local relations among completed records.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

Repeat the example with two operations per history. List every history and its parity class.

Exercise 2

A detector retains only the last letter of a three-letter history. How many records exist, and can it distinguish AAB from BAB?

Scope of this guideIntroductory finite counting and map examples. SMM supplies the common-source question; no geometry or physical dynamics is inferred from source unity alone.

Continue with the articles

- [The Single Monad Model of the Cosmos](#)

Introduce the Single Monad Model as a proposal connecting one generative source with the many events of experience. Set out its vocabulary before approaching its physical interpretations.

- [One action, two temporal roles](#)

Explain the draft's same-cycle foundation: inner action is primitive, while outer record order comes from completed observable returns. Neither role automatically supplies a second readable laboratory clock.

- [When two histories count as the same observation](#)

Introduce completion and observational equivalence as distinct ways of identifying histories. Explain why the tests available to an observer determine which differences survive.

Sources and reading

- [Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations](#)

Lesson 02: Inner work and the completed record

A result can become readable only after several dependent operations. DTT asks how that inner work and its completed record belong to one process.

<https://www.smonad.com/learn/02-inner-generation-and-completion.html>

The central connection

The six inner roles describe nested dependencies; the seventh is an outer completion interface. Neither nesting nor event count fixes elapsed physical time.

What you will learn

- Describe the difference between ordering, completion and duration.
- Calculate nested counter counts at a selected radix.
- Explain why a return requires a completion certificate and retained memory.

Before you begin: Lesson 01. You should understand a state, an update and a retained record.

An episode has internal work

Imagine preparing a document for release. Letters become words, words become checked sentences, and the finished document becomes available. These operations depend on earlier work, but readers need not observe every intermediate draft. DTT uses an analogous distinction between generative activity and completed observable configurations. The physical version must specify what performs the work and what makes the result available.

Three ideas require different tests. Order asks which operation came first. Completion asks whether the declared task is finished. Duration asks how much a calibrated clock advanced. Three completed documents might require three different preparation times. Likewise, counting completed source episodes does not establish that each episode occupies one equal physical tick.

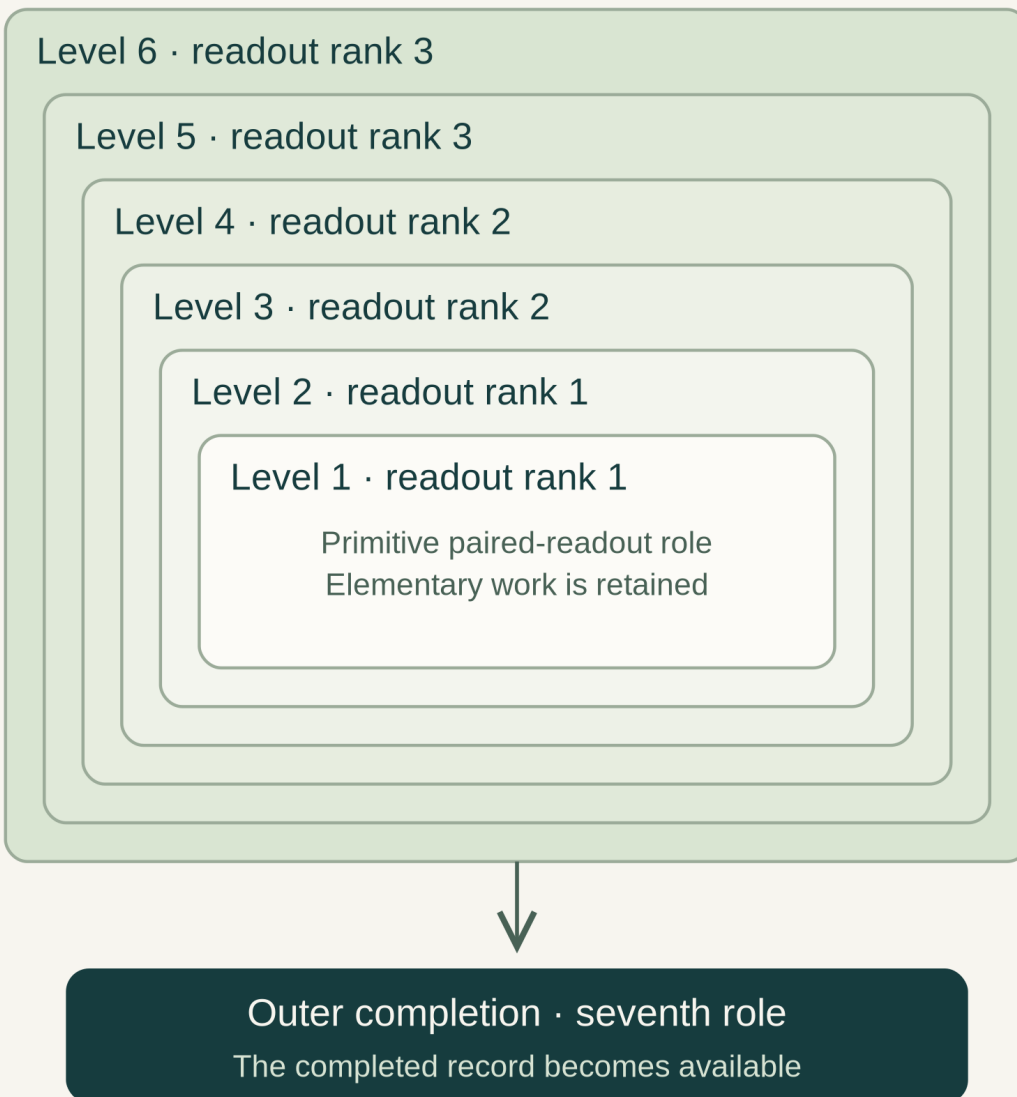
Six dependencies and one interface

The six inner roles in the nested formulation are organized so that higher roles depend on completed lower work. The seventh role exposes or certifies the assembled result. It is an outer completion interface, not another inner digit. This is the sense in which six inner roles can belong to one action rather than six freely adjustable temporal coordinates.

A useful picture is a counter with carries. The lowest digit advances first; a higher digit advances when a lower cycle is exhausted. All digits belong to one state and one update rule. The picture illustrates dependency, while the number and physical function of the stages must still be selected by an actual source model.

Six inner roles; one completion interface

Nested dependencies, not independent time axes



Conceptual dependency diagram; its paired-readout rank labels have the exact scope stated below. Each higher enclosure depends on lower-level work. The rank labels belong to the paired-readout example explained below. The drawing illustrates a dependency hierarchy, not six spatial shells or independent time axes. Open the full-size diagram →

A single update with nested periods

Choose a radix q , an integer at least two. Each digit d_a ranges from zero to $q-1$. In a six-digit counter the address is $n=d_1+qd_2+q^2d_3+q^3d_4+q^4d_5+q^5d_6$, with d_1 changing fastest. Incrementing n performs all necessary carries.

Beginning from zero, the first q^a addresses exhaust every combination of the first a digits while higher digits stay zero. Thus the first two binary digits visit 00, 10, 01 and 11 in that

least-significant-first notation. The four-state block has a precise boundary. A different initial address can encounter a carry sooner, so the initial preparation matters to the claimed hierarchy.

Worked example with the nested-generation demo

Open the nested-generation demonstration. Select radix two and role four. Four binary digits give $2^4=16$ addresses. The supplied paired readout has rank two because the first and second digits contribute opposite changes along one direction, while the third and fourth contribute along a second. At role six the count becomes $2^6=64$ and the rank becomes three.

Move to role seven. The count stays 64 and the rank stays three; the archive becomes marked as published. Now use radix three at role four: $3^4=81$ addresses still have rank two. More internal states do not automatically add a spatial direction. Lesson 04 derives the rank and explains exactly which readout assumptions make this statement true.

A return is useful when it certifies work

Suppose a phase marker returns to its starting position. That recurrence alone cannot establish that the record has passed a check: an unrelated rotating marker would also return. A completion mechanism must couple the flag to the actual work. One finite design computes a required parity, verifies it against a stored target and exposes a success bit only when they agree.

The model must also describe rejection and incomplete work. If failed attempts take time, a clock counting every attempt differs from an archive counting successes. Even perfect return to the same internal address does not retain the number of episodes. To distinguish the fifth completion from the sixth requires memory, a counter or another persistent record outside the resetting address.

What the calculation does and what comes next

The counter proves that one update can have nested periods and a separate publication boundary. It does not choose the length of a clock second, derive the supplied spatial frame or show that every physical clock ignores internal branch activity. These are specific next questions rather than defects in the exact counting result.

Compare a device that advances once per accepted archive with one that advances once per elementary counter operation. They agree on the order of completed archives but assign different readings during unfinished work. To turn either into a material clock, state its dynamics and calibration. Continue to observational equivalence to determine when the published record retains enough information to predict later tests.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

At radix three, how many addresses occur at roles two, five and seven? State the paired-readout rank at each.

Exercise 2

An episode visits eight internal addresses and succeeds independently with probability one half. With recoverable failure, how many attempts and internal visits are expected per success?

Scope of this guide Exact counter counts and stated retry arithmetic. The nested hierarchy, supplied paired readout and completion certificate remain declared architecture, with physical duration separately calibrated.

Continue with the articles

- One action, two temporal roles

Explain the draft's same-cycle foundation: inner action is primitive, while outer record order comes from completed observable returns. Neither role automatically supplies a second readable laboratory clock.

- Six inner stages and one publication interface

Explain the hierarchy of readout ranks 1, 1, 2, 2, 3, 3 followed by completion. These are nested functional roles rather than six independently readable temporal coordinates.

- What spatial readout forgets

Investigate information lost when a full generative state is reduced to spatial records. Explain why an apparently complete geometry may still be insufficient for autonomous prediction.

Sources and reading

- Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations

Lesson 03: When two records predict the same future

Two preparations can look identical now and behave differently later. A predictive record must preserve every distinction that the admitted future operations can expose.

<https://www.smonad.com/learn/03-observational-equivalence.html>

The central connection

Observational equivalence depends on the full family of allowed tests. Reduced dynamics closes only when hidden differences cannot change a later retained output.

What you will learn

- Construct a future test separating equal present observations.
- Check the finite linear condition for an autonomous retained update.
- Explain why discarded information can reappear as memory.

Before you begin: Lessons 01-02. The lesson introduces the needed two-coordinate matrix notation.

Ask the same future question of both preparations

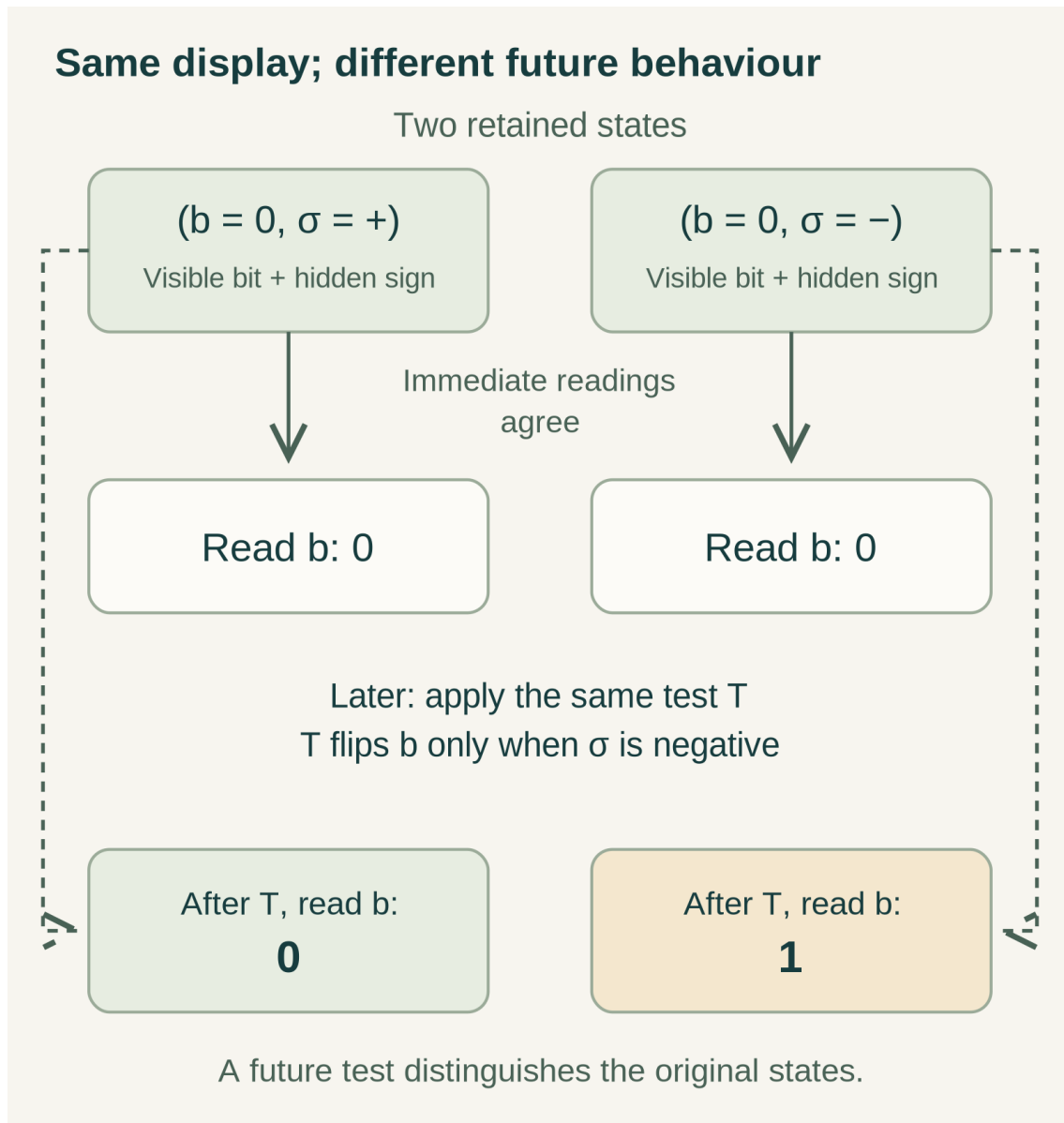
Equality of present display values is easy to test: compare the displays. Equality as predictive states asks more. Apply the same allowed processing to each preparation, then compare the resulting observations. If any admitted procedure separates them, the preparations cannot share one predictive label for that experiment.

This is an operational definition, not a demand to retain every imaginable hidden detail. A difference that no allowed preparation, operation or measurement can reveal need not become a public distinction. The family of tests sets the resolution of the description. Expanding that family can split an old equivalence class, so a model must say which controls belong to its experimental interface.

Worked example: a hidden control bit

Let the full state be (b,m) , with visible bit b and memory bit m . The current detector reports b . Compare $(0,0)$ and $(0,1)$: both display zero. Allow an update U that replaces b by $b \text{ XOR } m$ while retaining m . XOR means addition modulo two, so equal input bits produce zero and unequal bits produce one.

After U , the first state remains $(0,0)$ and the second becomes $(1,1)$. The same detector now reports different values. Therefore b alone cannot determine the next display under U . Retaining both bits repairs the prediction. Alternatively, remove U from the admitted controls; that changes the problem. Simply continuing to call the initial displays equivalent while using m later would leave the reduced update ambiguous.



Conceptual illustration of the same future-test principle using a hidden sign. The same display value need not imply the same predictive state. An allowed future test separates histories that an immediate bit detector cannot distinguish.

[Open the full-size diagram →](#)

When a reduced update is well defined

Let Π map a full state to its record. We seek an update V using only records, with $V(\Pi(z)) = \Pi(U(z))$. This is possible precisely when any two full states with the same record still have the same record after U . The necessity is immediate: a function V cannot assign two outputs to one input.

For sufficiency, choose any representative z of a record r and define $V(r) = \Pi(U(z))$. The condition ensures that another representative gives the same result. This is the whole content of a well-defined update on equivalence classes. If many controls are admitted, the condition must hold for the relevant completed sequences, not merely for one conveniently chosen operation.

An exact two-coordinate check

Write a linear update as $M(x,y)=(ax+by,cx+dy)$, where x is retained and y is hidden. The next visible coordinate is $ax+by$. Two states (x,y) and (x,y') therefore differ next by $b(y-y')$. Autonomy for every hidden input holds exactly when $b=0$.

$$P(x,y)=(x,0); \quad Q=I-P; \quad PM=TP \text{ exists exactly when } PMQ=0.$$

Here P keeps the retained component, Q keeps its complement, and I is the identity operation. Multiplying $PM=TP$ by Q gives $PMQ=0$. Conversely that condition implies $PM=PMP$, so the visible part of M provides T . This is an information projection on vectors; a physical quantum measurement will need the different instrument construction in Lesson 07.

The chosen boundary can restore autonomy

Rotate a real plane through an angle θ while retaining only its first coordinate. The visible intermediate value generally depends on the hidden second coordinate. Now follow the rotation by its inverse before exposing a completed record. Their product is the identity, so the final retained value equals its initial value regardless of hidden input.

This example shows why inner leakage and completed leakage are different tests. Completion can be a boundary at which a reduced update closes, even when intermediate stages do not. It does not show that every source undoes its work. The actual source law must determine the sequence, and the completion flag must certify that the boundary has been reached before the simplified record rule is used.

What to do when a record is too small

There are three constructive responses to failed autonomy: retain more state, restrict the operation language, or let predictions depend on a recorded history. The last option gives memory equations. Eliminating a relaxing hidden variable can produce an exponentially weighted integral of earlier visible values together with a term depending on hidden initial preparation.

That memory is meaningful, but a model with one ordinary time parameter and an auxiliary variable can already produce it. To establish a distinctive DTT restriction, derive the permitted memory and its relation to independently measured source responses. The records and memory guide supplies the full elimination. Carry this lesson into the binary spatial demo: an accurate current coordinate need not be a sufficient predictive state.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

For $M(x,y)=(3x+2y,y)$, compare initial states $(1,0)$ and $(1,4)$. Can a rule for x alone predict the next observation?

Exercise 2

A quarter-turn sends (x,y) to $(-y,x)$. Show what two quarter-turns do, and decide whether x alone predicts that completed result.

Scope of this guide Exact finite-state and finite linear criteria. The admitted controls determine equivalence; the information projection is not itself a quantum measurement instrument.

Continue with the articles

- When two histories count as the same observation

Introduce completion and observational equivalence as distinct ways of identifying histories. Explain why the tests available to an observer determine which differences survive.

- Test languages and observable quotients

Explore how richer tests alter the distinctions retained by a record model. Introduce the draft's correspondence between test languages and observational congruences.

- Retained observations versus predictive states

Ask when retained information is sufficient to predict future outputs autonomously. Explain the completion criterion and why keeping observations need not keep every dynamically relevant distinction.

Sources and reading

- Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations

Lesson 04: From six nested channels to three coordinates

A coordinate display can compress a much larger generative state. The paired-counter example lets us calculate direction, multiplicity and information loss separately.

<https://www.smonad.com/learn/04-nested-spatial-readout.html>

The central connection

The supplied signed pairing gives ranks 1,1,2,2,3,3 and maps 64 binary addresses to 27 sites. Uniform source sampling gives unequal site weights.

What you will learn

- Derive the paired-readout rank sequence.
- Calculate binary site multiplicities and probabilities.
- Distinguish an internal scan from physical motion and a spatial image from predictive memory.

Before you begin: Lessons 01-03. A vector direction means an independently variable coordinate; no prior linear algebra is required.

Supply a frame and define the readout

Choose three independent directions e_1, e_2, e_3 and a positive length ℓ . Independent means no direction can be formed by combining the other two. Use the six counter digits introduced in Lesson 02 and define a spatial candidate by pairing adjacent digits with opposite signs.

$$Q(d) = \ell[(d_1 - d_2)e_1 + (d_3 - d_4)e_2 + (d_5 - d_6)e_3].$$

This rule deliberately supplies a frame, a scale and a pairing. It gives a concrete question we can solve: what information appears in Q as nested digits become available? Showing the answer is exact for this construction is stronger than an analogy, while deriving why the source selects this particular construction remains another task.

Why the rank rises every second role

The rank here counts independent directions in the set of available outputs. When only d_1 varies, every output lies along e_1 . Allowing d_2 adds negative contributions along that same direction. It changes available positions, but cannot add a second direction. The third digit introduces e_2 ; its partner again adds no new direction.

Repeating the argument for the final pair gives ranks 1,1,2,2,3,3. Each newly claimed direction actually occurs by setting its first digit to one and the others to zero, so these are attained ranks rather than upper bounds. The result does not say that any imaginable six-stage process yields three-dimensional space. Its signed columns and independent frame do the mathematical work.

Worked example: count one pair first

For binary digits, one pair has four possibilities. The pairs (0,0) and (1,1) both give difference zero, while (1,0) gives +1 and (0,1) gives -1. Therefore the values -1,0,+1 have multiplicities 1,2,1. Under uniform preparation of the four pair states, their probabilities are 1/4,1/2,1/4.

Three independent pairs give $4^3=64$ addresses and $3^3=27$ coordinate triples. Multiplicities multiply: the origin has $2 \times 2 \times 2=8$ representatives, a site such as (1,0,0) has four, and (1,1,1) has one. Their probabilities are respectively 1/8, 1/16 and 1/64. The drawing is regularly spaced, but the declared sampling measure is visibly nonuniform.

Binary addresses; unequal site weights

One binary pair (a,b) gives $a - b$.

Four addresses; three possible differences.

-1 (0,1) Weight 1	0 (0,0), (1,1) Weight 2	+1 (1,0) Weight 1
--------------------------------	--------------------------------------	--------------------------------

Three pair factors: multiply their weights.

$z = -1$	$z = 0$	$z = +1$																											
<table> <tr><td>1</td><td>2</td><td>1</td></tr> <tr><td>2</td><td>4</td><td>2</td></tr> <tr><td>1</td><td>2</td><td>1</td></tr> </table>	1	2	1	2	4	2	1	2	1	<table> <tr><td>2</td><td>4</td><td>2</td></tr> <tr><td>4</td><td>8</td><td>4</td></tr> <tr><td>2</td><td>4</td><td>2</td></tr> </table>	2	4	2	4	8	4	2	4	2	<table> <tr><td>1</td><td>2</td><td>1</td></tr> <tr><td>2</td><td>4</td><td>2</td></tr> <tr><td>1</td><td>2</td><td>1</td></tr> </table>	1	2	1	2	4	2	1	2	1
1	2	1																											
2	4	2																											
1	2	1																											
2	4	2																											
4	8	4																											
2	4	2																											
1	2	1																											
2	4	2																											
1	2	1																											

Each number is an address multiplicity.

$$2^6 = 64 \text{ addresses} \rightarrow 3^3 = 27 \text{ sites}$$

Central site: 8 addresses

Each corner: 1 address

A many-to-one map; site weights are unequal.

Binary addresses; unequal site weights. Exact finite count for three independent binary-pair factors. The map produces 27 distinct sites from 64 addresses and does not produce a uniform site measure unless an additional weighting rule is supplied.

Open the full-size diagram →

Check the entire distribution

Group the sites by the number j of nonzero coordinates. There is one central site, six sites with one nonzero coordinate, twelve with two and eight with three. Their multiplicities are eight, four, two and one respectively. The site count is $1+6+12+8=27$ and the address count is $8+24+24+8=64$.

This gives a useful independent normalization check: the four class probabilities are $1/8, 3/8, 3/8, 1/8$ and sum to one. To sample sites uniformly would require a different preparation or weighting rule. For example, each address at site y could receive probability $1/[27M(y)]$, where $M(y)$ is that site's multiplicity. Summing its $M(y)$ contributions then gives exactly $1/27$.

The spatial display forgets a carry

Use the binary-spatial-readout demonstration at addresses zero and three. Their least-significant-first digit strings are 000000 and 110000. Both give $Q=0$. Increment each address once. Address one gives ℓe_1 , whereas address four gives ℓe_2 .

This is Lesson 03's failed-autonomy test in a spatial setting. An observer who retained only the current site could not know which successor to choose. Keeping the carry information repairs the prediction. The example also cautions against interpreting the counter's ordered scan as a particle trajectory: a carry can create a projected jump. A law of local motion on the retained sites must be specified and tested separately.

What three coordinates have established

We have an exact finite image with three independent directions, calculated multiplicities and a known loss of predictive information. We do not yet have a physical distance rule, an experimentally calibrated ruler or a bound on signal propagation. Even orthogonality was not required for the rank calculation; assigning Euclidean lengths would add a metric to the independent frame.

The deeper paired-rank derivation proves a six-channel lower bound under an opposite-pair architecture and explains alternatives outside those assumptions. The next lesson instead takes the generated-record perspective forward: choose which records are adjacent, derive distances from permitted comparisons, and determine whether the actual dynamics respects those relations.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

For the binary site $(-1,0,1)$, find its multiplicity and probability under uniform address sampling.

Exercise 2

At radix three, each digit is 0, 1 or 2. List the multiplicities of one difference and find the final site count and origin probability.

Scope of this guide Exact rank and counting for the declared paired map and uniform address preparation. Frame, metric, locality and transport require separate physical constructions.

Continue with the articles

- Six inner stages and one publication interface

Explain the hierarchy of readout ranks 1, 1, 2, 2, 3, 3 followed by completion. These are nested functional roles rather than six independently readable temporal coordinates.

- Generating a neighborhood and preserving local transport

Separate reconstruction of spatial adjacency from the requirement that subsequent dynamics remain local. Explain the guarded transport rules used to preserve the generated metric.

- What spatial readout forgets

Investigate information lost when a full generative state is reduced to spatial records. Explain why an apparently complete geometry may still be insufficient for autonomous prediction.

Lesson 05: Build distance and test local influence

A collection of coordinates becomes useful geometry when operations determine neighbours and comparisons determine lengths. The dynamics must then respect those same relations.

<https://www.smonad.com/learn/05-geometry-and-locality.html>

The central connection

Adjacency, metric and propagation are distinct outputs. A local completed circuit gives a graph support bound; a measured speed additionally needs length and clock calibration.

What you will learn

- Calculate weighted shortest-path distance.
- Explain why cubic adjacency does not automatically give Euclidean distance.
- Convert a local update bound into a conditional propagation-speed bound.

Before you begin: Lessons 01-04. You need addition, the triangle inequality and the distinction between a full state and its display.

Let operations define neighbours

Begin with completed record labels. Declare two labels adjacent when a permitted elementary comparison connects them. This produces a graph: labels are vertices and comparisons are edges. A drawing helps us see the graph, but positions on the page do not determine its operational geometry. Adding an edge between distant-looking labels makes them neighbours by definition of the permitted comparisons.

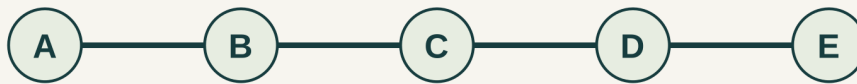
In an SMM construction, these edges should arise from the source's operation law and persistent memory. A programmed translation table can produce a regular lattice and establish possibility. Showing why that structure is selected and remains stable under allowed disturbances is a stronger physical result. Keep the preparation rule separate from the later dynamics acting on the prepared graph.

Local moves determine graph distance

Distance = fewest allowed edges between records.

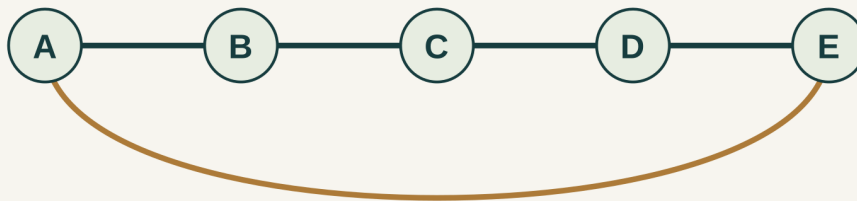
The same displayed positions can have another metric.

Allowed moves: nearest neighbours



$$d(A,E) = 4$$

Add one allowed move: $A \leftrightarrow E$



$$d(A,E) = 1$$

A locality model must justify its allowed edges.
Visual proximity alone does not define locality.

Local moves determine graph distance. Exact shortest-path distances in two specified finite graphs. The drawn shortcut represents a newly allowed elementary operation, not a consequence of the Euclidean positions used to display the graph.

Open the full-size diagram →

Worked example: the cheaper route sets distance

Assign positive costs to edges and define distance as the least total cost of a connecting path. Suppose A–B costs two, B–C costs three and A–C costs seven. The direct route from A to C costs seven, while the route through B costs $2+3=5$. The distance is therefore five.

This distance can also be read through constrained observables. Let f assign a real reading to each vertex, with differences no greater than an edge's cost. Along any path, the triangle

inequality bounds the total reading difference by the path cost. The choice $f(A)=0$, $f(B)=2$, $f(C)=5$ satisfies all three constraints and attains five. Local comparison limits have therefore reconstructed the same global distance.

Three directions do not choose one metric

Consider a square lattice with unit horizontal and vertical edges. From (0,0) to (1,1), every allowed shortest route has two steps, so graph distance is two. A Euclidean ruler laid across the drawing gives $\sqrt{2}$. These answers measure different permitted comparisons. Simply making axial edges finer preserves the same preference for axial travel unless the comparison procedure also changes.

Likewise, a three-dimensional cubic graph has a Manhattan distance equal to the sum of absolute coordinate differences. Its number of sites in a large region can grow like a radius cubed, while its norm remains different from Euclidean length. Rank, growth dimension and metric answer different questions. An isotropic physical limit needs a justified additional mechanism rather than a relabelling of one diagnostic.

A finite law that preserves local influence

Put a register at each vertex. Suppose one completed episode first acts within individual sites and then exchanges dedicated ports across neighbouring edges. Assume the edge layer consists of disjoint port exchanges and that no unlisted controller channel connects distant sites. An initially local disturbance can affect only its original site and adjacent sites during that episode.

Repeat the argument: after k episodes its influence is contained in the graph neighbourhood of radius k . This is an induction. The first episode gives the one-step claim; each later episode adds at most one edge to every possible influence path. The result is an exact causal support bound for this circuit architecture. It does not require pretending that an internal counter scan is itself particle motion.

Add a ruler and an actual clock

Let each edge have calibrated length ℓ and let every completed episode take duration Δt measured by a specified clock. The preceding support bound becomes a maximum slope $\ell/\Delta t$. For $\ell=3$ length units and $\Delta t=2$ time units, four episodes take eight time units and reach at most twelve length units, giving slope $3/2$.

A serial source may perform many internal operations to execute one episode, so assigning it the name tick does not establish Δt . Also inspect retained controller memory. A register that carries unknown information between distant sites creates a transport channel; its journey must be represented in the graph or excluded by the dynamics. Otherwise the claimed locality bound omits an actual route of influence.

Use separate tests before connecting the outputs

A practical geometry test first reconstructs adjacency from operations, then measures comparison lengths, then perturbs a local register and tracks accessible responses. Repeat after small changes to the source preparation. A robust construction should preserve its intended neighbourhoods and propagation rules together, with stated errors.

DTT makes the completion boundary especially important: the completed episode is where the retained graph and support statement are assessed. Six nested inner roles may organize the preparation, while the outer interface certifies the result. The locality guide develops the exact support proof and the metric guide develops normalized comparisons. Lesson 06 turns to another needed structure: a phase carrier supporting coherent dynamics before registration.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

If the direct A-C edge is changed from seven to four, calculate $d(A,C)$ and exhibit a permitted reading f that attains it.

Exercise 2

A disturbance is five edges from a detector. One episode permits one edge of influence, takes three clock units and each edge is two length units. Find the earliest allowed arrival and maximum slope.

Scope of this guide Exact graph and finite-circuit results under declared edges, positive weights and local gates. Physical rulers, episode duration, isotropy and controller restrictions are additional data.

Continue with the articles

- Why local geometry can be statistically rare

Explain the entropy barrier to lattice-like relational memories in the stated permutation ensemble. The result concerns a specified preparation problem, not every possible mechanism for emergent space.

- Generating a neighborhood and preserving local transport

Separate reconstruction of spatial adjacency from the requirement that subsequent dynamics remain local. Explain the guarded transport rules used to preserve the generated metric.

- A finite-update cone

Introduce the bound relating horizontal displacement to temporal projection in the limiting-speed draft. Explain that the finite-update inequality is a stated geometric assumption.

- Graph distance from a normalized spectral block

Introduce the graph-block construction whose Connes distance equals weighted shortest-path distance. Explain the normalization assumptions behind that equality.

Lesson 06: Recover a complex phase from real rotation

Ordinary complex multiplication can be represented by a real quarter-turn. This makes phase a concrete operation that can be checked before adding a quantum measurement rule.

<https://www.smonad.com/learn/06-complex-phase.html>

The central connection

An invertible skew generator selects $J=A(-A^2)^{-1/2}$ on its dynamic sector. For forward $A=J\Omega$ and positive $H=a\Omega$, conventional Schrödinger notation uses $i=-J$.

What you will learn

- Verify that a real quarter-turn squares to minus the identity.
- Separate rotation rate from phase orientation by polar normalization.
- Distinguish ordinary complex phase, split-complex geometry and physical time calibration.

Before you begin: Lessons 01-05. Basic coordinates are sufficient; operator multiplication means applying one rule after another.

Begin with a rule on a real plane

Define $J(x,y)=(-y,x)$. A point on the positive horizontal axis moves to the positive vertical axis, so J is a counterclockwise quarter-turn. Apply it again: $J(-y,x)=(-x,-y)$. Two applications reverse every vector, which is written $J^2=-I$, where I leaves vectors unchanged.

The ordinary imaginary unit i obeys $i^2=-1$. We can therefore represent one complex convention by letting multiplication by i act as J on this real plane. This operation does not introduce an extra physical dimension or clock. It equips an existing two-real-component carrier with a consistent scalar multiplication. Its norm is preserved because $(-y)^2+x^2=x^2+y^2$.

Worked example: watch the rotation

Open the phase-rotation demonstration and select $\theta=30$ degrees. The unit vector is $\psi=(\sqrt{3}/2,1/2)$. Applying J gives $(-1/2,\sqrt{3}/2)$, and applying it again gives $(-\sqrt{3}/2,-1/2)$. Every vector has squared norm $3/4+1/4=1$.

For any angle, the rotation is $\exp(\theta J)=\cos\theta I+\sin\theta J$. Grouping even and odd powers in the exponential series proves the identity because $J^2=-I$. The slider sets a dimensionless angle. To convert it to elapsed time, supply a phase rate ω and a clock relation $\theta=\omega t$. Merely labelling an angle inner time does not calibrate that relation or explain how a detector reads it.

Let the dynamics choose orientation

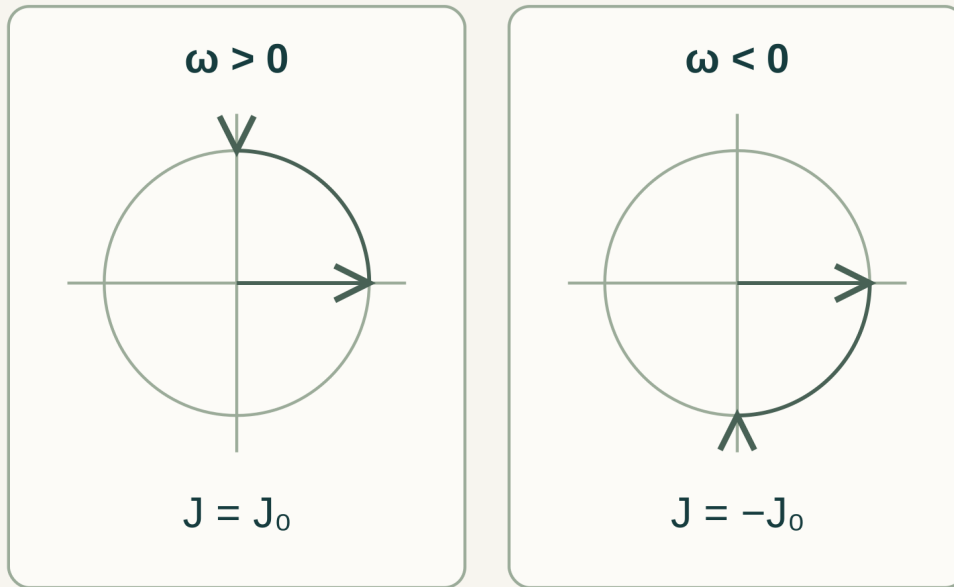
Suppose a real norm-preserving continuous evolution has generator A with $A^T = -A$ and no stationary direction. Its positive magnitude is $\Omega = (-A^2)^{1/2}$. In finite dimensions Ω commutes with A and is invertible. Define $J = A\Omega^{-1}$. Then $J^2 = A^2\Omega^{-2} = -I$: removing the rate leaves an oriented quarter-turn structure.

For $A = 3J_0$, the magnitude is $3I$ and $J = J_0$. For $A = -3J_0$, the magnitude remains $3I$ while $J = -J_0$. Thus the direction of evolution, not just the unoriented circle, supplies the sign. This exact selection assumes the oriented generator already exists; it does not by itself derive the source dynamics producing that generator.

Polar phase retains orientation

$$A = \omega J_0, J_0(x, y) = (-y, x), \omega \neq 0$$

$$-A^2 = \omega^2 I; J = A(-A^2)^{-1/2}$$



$$J = \text{sign}(\omega) J_0$$

$$J^2 = -I \text{ in both cases}$$

Normalization removes the nonzero frequency scale.

It retains the direction of phase rotation.

At $\omega = 0$, this polar formula is undefined.

Polar phase retains orientation. Exact two-dimensional polar calculation on an invertible skew block. Zero-frequency directions require separate treatment; the figure does not identify this ordinary complex structure with the split-complex unit of hyperbolic geometry. [Open the full-size diagram →](#)

Keep the forward-flow sign consistent

Now write the forward real evolution as $d\psi/dt = A\psi = J\Omega\psi$. Choose a positive action constant a and define $H = a\Omega$, which is positive on the dynamic sector. Conventional Schrödinger notation is $i\hbar d\psi/dt = H\psi$. These expressions agree when its scalar i is represented by $-J$.

$$(-J)a(J\Omega\psi) = a\Omega\psi = H\psi.$$

Choosing $i=j$ instead would give $i a \, d\psi/dt = -a\Omega\psi$ for this same forward flow. Either scalar convention is mathematically possible, but the sign of the Hamiltonian and orientation must be tracked together. The earlier quarter-turn exercise establishes an ordinary complex structure; it does not require identifying that convention with the conventional positive-energy i without this additional sign choice.

Stationary directions and another algebra

If A vanishes on a direction, Ω has a zero eigenvalue there and its inverse cannot be used. The polar construction selects phase on the dynamic sector, the complement of the stationary kernel. A stationary real line cannot carry an operator squaring to $-I$; a stationary plane admits such operators but the zero dynamics does not choose their orientation.

Split-complex notation uses a different unit j with $j^2 = +1$. Its exponential is $\cosh\eta + j \sinh\eta$ and preserves an indefinite quadratic form in the appropriate real representation. Ordinary $J^2 = -I$ gives circular phase. Split-complex $j^2 = +1$ gives hyperbolic mixing. Similar notation is no reason to exchange these identities or identify a quantum phase coordinate directly with spacetime.

What phase contributes to the course

SMM asks whether one source can generate the mathematical structures used across physics. The polar result supplies a precise conditional dependency: an oriented real orthogonal dynamics selects a compatible phase on its moving sector. DTT then asks how that internal coherent activity becomes an available record.

A phase structure alone does not fix which outcomes are possible, their probabilities, how separate systems compose or which action unit relates frequency to energy. Those ingredients must be supplied or derived through additional constructions. Lesson 07 introduces an explicit quantum instrument and checks its normalization. For the broader proof and symmetry-compatibility questions, read [real dynamics and phase](#), including its treatment of stationary modes.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

$A = \text{diag}(2J_0, -5J_0)$ acts on two real planes. Find Ω and J , and verify the sign choice for $H = a\Omega$.

Exercise 2

Compare $J(x,y) = (-y,x)$ with $S(x,y) = (y,x)$. What is each square, and which quadratic form does $\exp(\eta S)$ preserve?

Scope of this guide Finite real-plane and invertible skew-generator calculations. Zero modes, composition, probability, source selection and physical action or clock calibration remain separate requirements.

Continue with the articles

- [Split-complex time and ordinary quantum phase](#)

Explain why the split-complex pairing used for temporal roles differs from the ordinary complex scalar selected for phase. Avoid treating two algebraic uses of complex language as identical.

- Selecting phase by polar decomposition

Explain how a positive-time generator can select a compatible complex structure on the dynamic sector. Make clear why zero-frequency modes need separate treatment.

- Real-commutant phase selection: a paper guide

Introduce the paper's phase-selection question in real Hilbert representations. Prepare an accessible route from the commutant to compatible complex structures and their physical interpretation.

Sources and reading

- Real-commutant phase selection from real Hilbert representations
- Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations

Lesson 07: Quantum states, completion flags and memory

Phase-sensitive states and readable outcomes require different descriptions. A quantum instrument specifies both the probability of a record and the change caused by recording it.

<https://www.smonad.com/learn/07-quantum-states-and-records.html>

The central connection

A complete instrument includes all outcomes. Completion can be unbiased with respect to an unknown payload while still depending on source preparation and apparatus resources.

What you will learn

- Calculate probabilities and conditional states in a two-outcome measurement.
- Compare coherent evolution before and after registration.
- Derive retry probabilities with explicit recovery and independence assumptions.

Before you begin: Lessons 01-06. This lesson introduces two-component quantum states and supplies the measurement rule it uses.

Supply the quantum framework explicitly

A normalized two-level pure state is $\psi = a|0\rangle + b|1\rangle$, where a and b are complex amplitudes and $|a|^2 + |b|^2 = 1$. In the measurement rule used here, a detector of the displayed basis reports zero with probability $|a|^2$ and one with probability $|b|^2$. We are supplying this quantum rule to study a completion mechanism; the preceding phase construction alone did not derive it.

A density matrix ρ describes pure preparations and probabilistic mixtures in one language. For a pure state it is $|\psi\rangle\langle\psi|$. Its trace equals one. Off-diagonal entries carry coherence relative to the selected basis, which can affect later phase-sensitive tests even when the immediate basis probabilities coincide.

Worked example: write every outcome

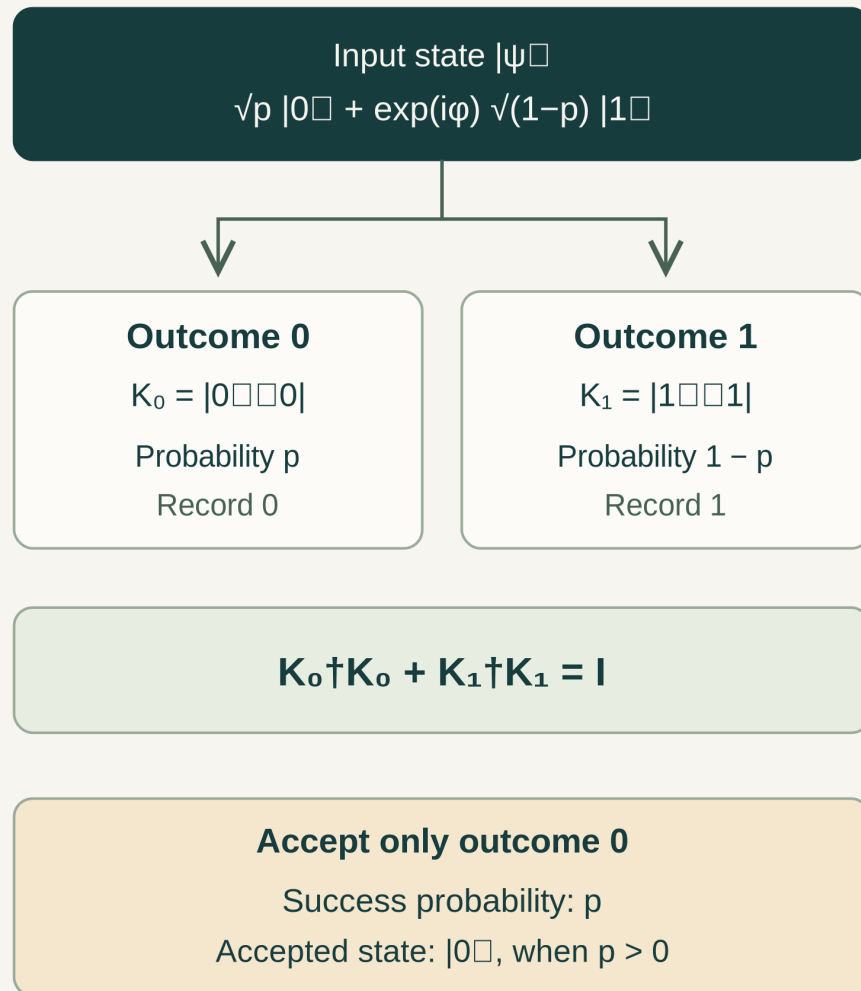
Prepare $\psi = (\sqrt{3}/2)|0\rangle + (1/2)|1\rangle$. The projectors $P_0 = |0\rangle\langle 0|$ and $P_1 = |1\rangle\langle 1|$ define unnormalized outcome maps $I_k(\rho) = P_k \rho P_k$. Their traces are $3/4$ and $1/4$, which sum to one. Conditional on the first result, the normalized state is $|0\rangle\langle 0|$; conditional on the second, it is $|1\rangle\langle 1|$.

If the apparatus performs the measurement but its result is ignored, the remaining state is $\text{diag}(3/4, 1/4)$. The input's off-diagonal entries $\sqrt{3}/4$ have vanished. Keeping only successful zero records would instead report a pure zero state together with success probability $3/4$. Omitting that probability would hide the discarded trials and misdescribe the operation.

Completion instruments and records

A complete two-outcome measurement instrument

$0 \leq p \leq 1$; φ is a relative phase



The full ensemble includes both recorded outcomes.

Completion instruments and records. Exact normalized projective-instrument example. Calling one outcome a completion success is an additional operational choice, and postselection must retain its success probability. [Open the full-size diagram →](#)

Completion requires the entire instrument

More generally, outcome operators M_k obey $\sum_k M_k^\dagger M_k = I$. This identity ensures that the sum of outcome probabilities is one for every input. The unnormalized map, its trace and the normalized conditional state are three distinct objects. Conditional normalization is meaningful only when the selected outcome has nonzero probability.

In DTT terms, a work register can evolve internally before a completion flag exposes a result. The flag must be produced by the specified dynamics and correlated with an actual completion

condition. Calling a projector completion does not explain how a physical apparatus produces or retains the flag. The state of the work register, accepted and rejected outcomes, and later memory readout all belong to the model.

Registration changes what later work can use

Let $|+\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$ and let H be the Hadamard operation, which sends $|+\rangle$ to $|0\rangle$. Write D for an unread measurement in the zero-one basis. Compare D followed by H with H followed by D , using the same initial state and final basis detector.

In the first protocol, D removes coherence and gives $1/2$. A unitary H leaves $1/2$ unchanged, so the final outputs are balanced. In the second protocol, H first produces $|0\rangle$, which D leaves unchanged; the final result is certainly zero. The difference is standard quantum registration physics. A distinctive source proposal must predict how its actual registration operation couples to inner work, rather than treating this familiar contrast as evidence by itself.

A completion that preserves an unknown payload

Choose $M_{\text{acc}} = \sqrt{p} V$ and $M_{\text{fail}} = \sqrt{(1-p)} W$, with fixed unitaries V, W and $0 < p \leq 1$. The squared effects sum to I , and acceptance has probability p for every normalized payload. The accepted conditional state is $VpV^\dagger$. On failure, applying $W^\dagger$ restores the original state, including correlations with a passive reference.

With fresh independent apparatus and the same p on each restored attempt, first success at attempt n has probability $(1-p)^{n-1}p$. The mean attempt count is $1/p$. These statements require the failure recovery and fresh preparation just specified. An arbitrary rejected branch can leak information irreversibly, in which case restoring the payload and applying this geometric retry law are not justified.

A result must remain available

After successful writing, test whether the record remains readable at declared later delays. A perfect initial flag and a rapidly overwritten memory do not provide the same operational resource as a protected record. Completion accuracy, payload disturbance and retention lifetime need separate measurements, even when a common source supplies all three mechanisms.

The course now connects its two meanings of sufficient information. Lesson 03 asked whether a record predicts future tests. This lesson asks how an instrument prepares that record and changes the state. The [completion guide](#) expands the instrument and recovery examples. A common source explanation becomes stronger when one fixed dynamics constrains both its coherent phase and its readable outcomes.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

For recoverable independent attempts with $p=1/4$, calculate the probability of first success on attempt three, the probability of success within three attempts, and the mean attempt count.

Exercise 2

Start with $|+\rangle$ and apply an unread zero-one measurement. What remains, and why can a final Hadamard not recover a certain zero output?

Scope of this guide Exact two-level calculations within supplied quantum mechanics. The probability rule, unitary controls, recoverable failures and fresh trials are assumptions, not consequences of completion terminology.

Continue with the articles

- A quantum source for generation and completion

Introduce the positive phase-dilation model as an explicit realization within quantum mechanics. Explain how it distinguishes inner work from completed observation without deriving quantum kinematics itself.

- Completion without biasing an unknown input

Explain the construction of a loaded completion channel with input-independent success probability. Clarify why this condition matters when the matter state is unknown.

- Undoing rejected partial work

Explore coherent recovery after a failed completion attempt, including inputs entangled with a reference. Explain the inverse access and control resources needed for the construction.

- Reliable completion by repeated attempts

Explain the geometric success law for fresh, recoverable attempts and the finite-archive reliability bound. Relate reliability to resource budgets rather than an assumption of guaranteed completion.

- A record that carries its own completion certificate

Introduce autonomous generation of a record and a flag certifying completion. Explain why the certificate must arise from the specified dynamics rather than an external declaration.

- Keeping an observed label stable

Study repeated interrogation of a stored label, including selective measurement backaction. Explain the transport assumptions that preserve the label and the errors they allow.

Lesson 08: Calibrated clocks and relativistic duration

An ordered archive is not yet a clock. A physical clock compares a repeatable process with a calibrated reading, and relativity supplies a benchmark for its response to motion.

<https://www.smonad.com/learn/08-clocks-and-relativity.html>

The central connection

Proper time is a path-dependent metric quantity. A source oscillator measures it only when its readable relative phase follows the same law with retained cycle count.

What you will learn

- Calculate proper time for constant-speed and piecewise constant-speed paths.
- Distinguish accumulated clock duration from received signal frequency.
- Identify the calibration and universality requirements for a DTT clock.

Before you begin: Lessons 01-07. Square roots and the meaning of speed as distance divided by time are sufficient.

Give the clock an operational reading

A clock needs a repeatable process, a rule for accumulating cycles and a calibration assigning units. A circular hand alone forgets how many turns have passed. A retained counter can distinguish a phase after one turn from the same phase after a thousand. DTT's outer record must carry enough memory for this distinction if the reading is to measure accumulated duration.

Earlier lessons separated internal update count from completed event count. A clock may couple to either, or to another combination. Its dynamics decides. Comparing two clocks requires preparing and calibrating them together, applying a declared protocol and comparing their later readings. Agreement for one preparation does not establish agreement for every allowed motion or source operation.

The relativistic benchmark

Supply flat spacetime with invariant speed c . Along a massive clock moving at speed v relative to inertial coordinates, the interval relation is $c^2 d\tau^2 = c^2 dt^2 - dx^2$. Substituting $dx = v dt$ gives $d\tau = dt \sqrt{1 - v^2/c^2}$. The positive root represents the forward proper duration accumulated along the clock's path.

$$\beta = v/c; \quad \gamma = 1/\sqrt{1 - \beta^2}; \quad \Delta\tau = T\sqrt{1 - \beta^2} = T/\gamma.$$

The last expression assumes constant speed for coordinate duration T . If speed changes, calculate the integral along the full path or add the contributions of constant-speed segments.

Here the metric is an input. Recovering this clock law from a source construction is a substantive additional result, not a consequence of having an internal phase.

Worked example: two bars on one scale

Use the proper-time demonstration with $T=10$ and $\beta=0.6$. The rate factor is $\sqrt{1-0.36}=0.8$, the Lorentz factor is 1.25, and the moving clock accumulates $10 \times 0.8 = 8$ time units. Both bars use the same units, so their difference is two.

At $\beta=0$, the factor is one and both readings agree. At a larger subluminal speed, the moving clock accumulates less proper duration over the same coordinate interval. These statements compare ideal clock readings through an inertial timing procedure. They do not directly state the frequency seen in incoming light pulses, which also depends on signal propagation and Doppler effects. Those effects require their own exchange calculation.

Compare clocks where they meet again

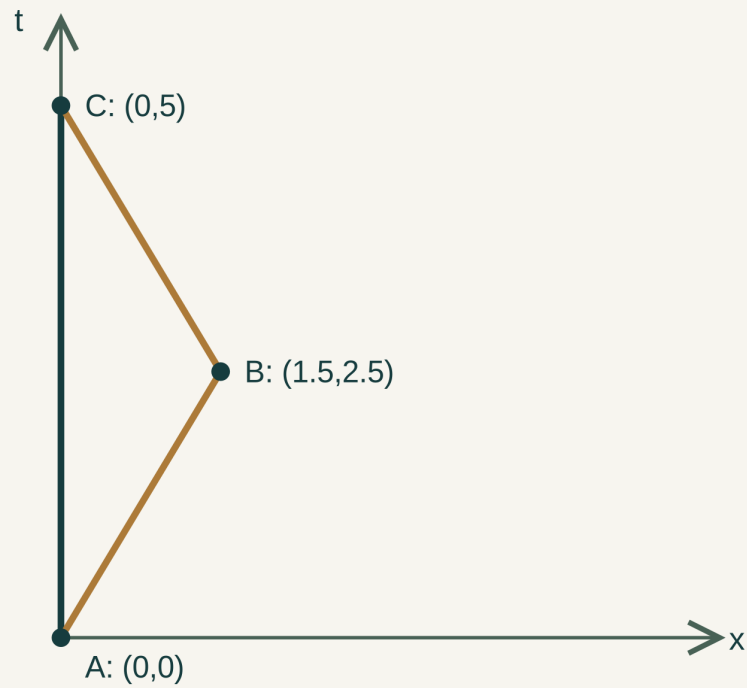
A reunion makes comparison local. In units $c=1$, let one clock remain at $x=0$ for five coordinate-time units. Let another move outward at speed 0.6 for 2.5 units and return at the same speed for 2.5. Its turning point is $x=1.5$. In the ideal limit of a negligible turnaround duration, the traveller accumulates $2.5 \times 0.8 + 2.5 \times 0.8 = 4$.

The stationary clock accumulates five. The difference follows from integrating along the two paths. A finite turnaround must be included using its actual speed profile; no separate mysterious ageing penalty is assigned to acceleration. The following figure displays this exact piecewise-inertial benchmark under the stated idealization.

Elapsed time depends on the path

Flat spacetime; units with $c = 1$

Two ideal clocks reunite at the same event.



Straight clock: $\Delta\tau = 5$

Two-leg clock: $\Delta\tau = 2\sqrt{(2.5^2 - 1.5^2)} = 4$

Each leg has speed $|v| = 0.6$.

Idealized instantaneous turnaround at B.
Coordinates are (x,t) ; both paths are timelike.

Elapsed time depends on the path. Exact flat-spacetime proper times for the stated piecewise inertial paths, in units $c = 1$. The turnaround is idealized; a smooth acceleration produces a nearby result when its duration is small.

[Open the full-size diagram →](#)

How a relative phase can measure duration

Suppose a stable transition has rest angular frequency ω_0 and obeys $d\phi = \omega_0 d\tau$. Its unwrapped phase then gives $\tau = (\phi - \phi_0)/\omega_0$. This is a clock realization once the coupling law and readout are established. An arbitrary oscillator could instead follow coordinate time or some internal work count, so recurrence alone does not choose the proper-time response.

A global phase multiplying one isolated state is not a directly readable hand. A clock uses a relative phase between states or paths and an apparatus that can compare it. This connects Lesson 06's phase carrier with Lesson 07's instrument and the earlier requirement for memory: phase coherence, cycle count and measurement all enter a usable clock.

The common-source target

A successful SMM/DTT construction would explain why different stable material clocks, after calibration, measure the same proper-time functional in their ideal regimes. It would connect their response to the metric used by rulers and signals. A protected logical clock that ignores one selected class of inner operations is useful but does not alone prove this universal relativistic response.

Keep the six inner roles as nested dependencies, not extra durations added to τ . The seventh role makes the accumulated clock record available. The proper-time guide extends the benchmark to gravitational lapse and matter phase. The clock-selection comparison asks which source restrictions exclude alternative clock couplings across multiple preparations.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

A clock moves at speed $0.8c$ for twelve coordinate-time units. Find its Lorentz factor, proper duration and difference from a stationary clock over that interval.

Exercise 2

A path consists of three coordinate-time units at rest, then five units at speed $0.6c$. Calculate its total proper time and the phase count for a clock making two cycles per unit proper time.

Scope of this guide Exact ideal-clock calculations in supplied flat spacetime, with an explicitly idealized turnaround. Universal source-derived clock response, material imperfections and received frequencies require separate models.

Continue with the articles

- When an additive clock is unique

Explain the conditional uniqueness of a scalar clock up to positive rescaling for ordered rank-one returns. Distinguish additive delays from a globally defined event time.

- A protected material clock

Describe the model that realizes resolution-only evolution through protected couplings. Explain which interaction restrictions protect the clock and how a controlled perturbation breaks that protection.

- Why one clock model does not prove universality

Use the ungated-clock countermodel to show that a realizable clock law need not be physically universal. Explain the extra selection principle required for all material clocks to agree.

- Calibrating a conformal geometry

Explain why a causal cone fixes less than a fully scaled metric. Introduce the record-density and clock standards used to supply the remaining scale in the draft.

Sources and reading

- David Tong, General Relativity: Geodesics in Spacetime

Lesson 09: Local frames and observable loop comparisons

A change in local description can alter every link without altering the completed comparison. Gauge theory makes that distinction precise through transport and loop invariants.

<https://www.smonad.com/learn/09-symmetry-and-gauge.html>

The central connection

Endpoint frame changes cancel around an Abelian loop. The resulting invariant is a possible comparison observable, while a group choice, field dynamics and physical detector require further input.

What you will learn

- Apply the endpoint rule for a local phase-frame change.
- Calculate a loop phase and show its invariance.
- Distinguish an invariant mathematical quantity from an accessible measured response.

Before you begin: Lessons 01–08, especially circular phase and quantum registration. Angles may be calculated in degrees in the worked examples.

Ask what a transformation preserves

A symmetry is described relative to data it preserves. Rotating a Euclidean vector preserves its length; permuting labels can preserve a graph. A change of basis instead changes the description of the same represented object. In a physical problem, specify whether a transformation acts on the system, the observer or the coordinates before drawing conclusions from the word symmetry.

Gauge freedom concerns local choices of representation. Different record locations can carry phase-bearing states without a preferred common phase convention. A transport rule tells us how to compare them. For SMM/DTT, this is a concrete way to ask how completed records share relational phase information even when their individual local labels depend on convention.

Derive the link transformation

At vertex j let a component transform as $\psi'_j = \exp(i\chi_j)\psi_j$. A link $U_j = \exp(i\alpha_j)$ carries the component from j to $j+1$. For the transported result to transform in the arrival frame, the new link must obey $U'_j = \exp(i\chi_{j+1})U_j\exp(-i\chi_j)$.

$$\alpha'_j = \alpha_j + \chi_{j+1} - \chi_j.$$

The two extra terms refer to the endpoint conventions. They do not represent a new physical rotation applied to the carrier. Changing an actual link phase while holding frames fixed is a

different operation. A calculation becomes interpretable only after this distinction between transport data and their local representation is kept explicit.

Worked example: four links close the path

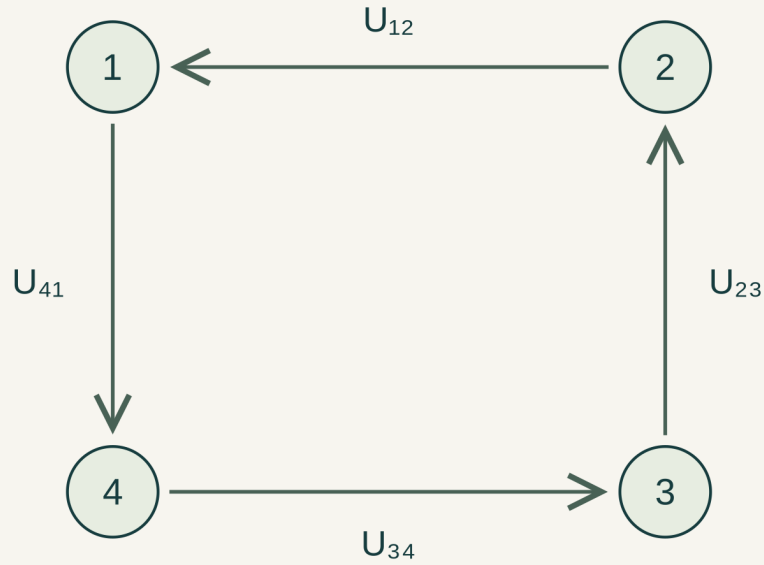
Use the gauge-holonomy demonstration with link angles 30, 45, -15 and 60 degrees. Their sum is $\Phi=120$ degrees. The loop product is $W=\exp(i\Phi)$, so its real part is $-1/2$ and its imaginary part is $\sqrt{3}/2$. In the one-dimensional $U(1)$ representation its trace is simply this same complex number.

Change only the first frame to $\chi_1=30$ degrees. The first link becomes zero and the fourth becomes 90; the middle two remain 45 and -15. Their sum is still 120. Algebraically all frame terms cancel in the closed sum because each vertex appears once as an arrival and once as a departure. This is exact cancellation, not averaging over uncertain frames.

Transport around a closed loop

U_i transports a vector at j to the frame at i .

Change frames: $U_i \rightarrow g_i U_i g_i^{-1}$



Closed transport: $W = U_{12}U_{23}U_{34}U_{41}$

$W \rightarrow g_1 W g_1^{-1}$

Therefore $\text{tr } W$ is frame independent.

Gauge invariance constrains observables, not their weights.

Transport around a closed loop. Exact transformation rule for invertible frame changes and consistent link orientation. For compact gauge theories the links are typically unitary. This identity alone does not choose a gauge group or a dynamical action.

Open the full-size diagram →

Make the phase relative to a reference

A global phase multiplying a single isolated state leaves its density matrix unchanged. To observe the loop phase, supply a coherent reference. In an ideal balanced two-arm comparison, one arm acquires $\exp(i\Phi)$ while the other does not. Recombination gives plus-port probability $P_+ = (1 + \cos\Phi)/2$.

For the worked loop, $\cos 120^\circ = -1/2$, giving $P_+ = 1/4$. This is a concrete detector prediction under the additional interferometer assumptions. Reading $\cos \Phi$ alone cannot separate Φ from $-\Phi$; another phase setting can recover the missing quadrature. If path coherence is lost, the ideal fringe disappears. Thus gauge invariance identifies suitable information, while preparation and readout decide whether the experiment can actually access it.

What survives for matrix-valued transport

For higher-dimensional carriers, links are matrices and their order matters. Around a loop based at v , a frame change h_v transforms the product as $W' = h_v W h_v^{-1}$. The trace and eigenvalues survive conjugation even though individual entries change. The identity follows by cancellation of adjacent endpoint transformations in the ordered product.

This calculation does not determine which gauge group nature uses, what action governs its fields or what sets its coupling. Those are dynamical and physical selection questions. Likewise, invariance alone supplies no Yang–Mills mass-gap result. A source reconstruction must derive its carrier, admissible comparisons and dynamics before importing conclusions from a more specific gauge theory.

Connect the loop to a source protocol

A loop may be a path through spatial records or a controlled cycle in parameter space. A DTT interpretation must say which, then derive the corresponding transport from its source update. The six nested roles can organize dependent operations; their number alone does not assign an angle to the completed loop.

Design a useful comparison by fixing the source preparation, varying a declared loop protocol and retaining an independently defined detector output. Include a control where the effect vanishes. The holonomy guide gives an example of structure hidden in an inaccessible sector, reinforcing Lesson 03's test-language principle. Next we use a specified interaction to build a quantitative matter example: a bound Coulomb state.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

For link angles (10,20,30,40) degrees and vertex frame shifts (5,−5,10,0), calculate every transformed link and the loop sum.

Exercise 2

An ideal balanced interferometer measures a loop with $\Phi = 60$ degrees. Find its plus-port probability. Would measuring only that probability distinguish $\Phi = -60$ degrees?

Scope of this guide Exact Abelian link arithmetic and matrix conjugation identities with a supplied coherent comparison instrument. No gauge group, force law, coupling or Yang–Mills gap is derived.

Continue with the articles

- Relational transport and gauge freedom

Explain why independently unframed record fibers require a rule for comparison. Introduce gauge transport as a conditional reconstruction idea, distinct from the draft's exact Hamiltonian results.

- An exact singlet-loop response

Introduce the four-position mobile carrier and stationary dual used in the solvable model. Explain how the holonomy-dependent resolvent determines the ground-state response under the supplied Hamiltonian.

- Invisible holonomy in inaccessible sectors

Explain the draft's classification of residual parallel monodromy invisible to the prepared interface. Nontrivial structure can survive outside the behavior an experiment can access.

Lesson 10: Binding, hydrogen and the meaning of speed

A persistent record becomes a matter model when a specified dynamics supports stable states. Hydrogen provides linked tests of localization, energy and momentum once its Hamiltonian is declared.

<https://www.smonad.com/learn/10-matter-and-hydrogen.html>

The central connection

The supplied Coulomb model fixes radius and binding energy together. Its ground-state relative RMS speed is gc , while the real 1s probability current is zero.

What you will learn

- Minimize the exponential-family Coulomb energy.
- Connect radius, binding energy and relative momentum using one Hamiltonian.
- Separate relative RMS speed, electron centre-of-mass speed and probability current.

Before you begin: Lessons 01-09. This lesson supplies its quantum Hamiltonian and uses elementary differentiation and normalized-state expectations.

State what makes the pair bind

Neutrality alone does not establish an atom: two opposite charges can be far apart. Binding requires a localized state below the energy of separated constituents. Supply a three-dimensional relative-coordinate Hamiltonian $H = -D\nabla^2 - C/r$, with positive D and C and separation threshold zero. The first term is a kinetic cost; the second is attractive.

For an electron of mass m_e and nucleus of mass M , the reduced mass is $\mu = m_e M / (m_e + M)$. Conventional matching sets $D = \hbar^2 / (2\mu)$ and $C = g\hbar c$. The dimensionless g becomes the electromagnetic coupling after matching to that physical interaction. Geometry, coherent dynamics, the inverse-distance potential and their coefficients are inputs to this lesson's calculation.

Worked example: find the preferred size

Take the normalized exponential $\psi(r) = \exp(-r/a) / \sqrt{(\pi a^3)}$, where $a > 0$ controls its spatial size. Its exact expectation in the supplied Hamiltonian is $E(a) = D/a^2 - C/a$. Differentiating gives $E'(a) = -2D/a^3 + C/a^2$, which vanishes at $a_* = 2D/C$.

$$a_* = 2D/C; \quad E_* = -C^2/(4D).$$

For $D = 1/2$ and $C = 1$ in model units, the radius parameter is one and the energy is $-1/2$, below the separation threshold. This is a minimum within the trial family. The full Coulomb derivation

supplies a square-completion lower bound for all admissible states and shows that the optimized exponential is the exact ground state of this operator.

Compare the entire binding curve

Set $x=a/a_*$ and divide energy by $|E_*|$. The hydrogen-energy demonstration plots the resulting function $1/x^2-2/x$. Its value plus one equals $(1/x-1)^2$, proving the minimum is -1 at $x=1$.

At $x=1/2$, kinetic and potential contributions are four and minus four, giving zero. At $x=2$ they are $1/4$ and minus one, giving $-3/4$. The curve captures the balance between confinement cost and attraction. Doubling C at fixed D halves a_* and quadruples $|E_*|$ but leaves this dimensionless curve unchanged. Therefore the existence or shape of the bound curve cannot select a numerical coupling by itself.

A probability profile is not an orbit

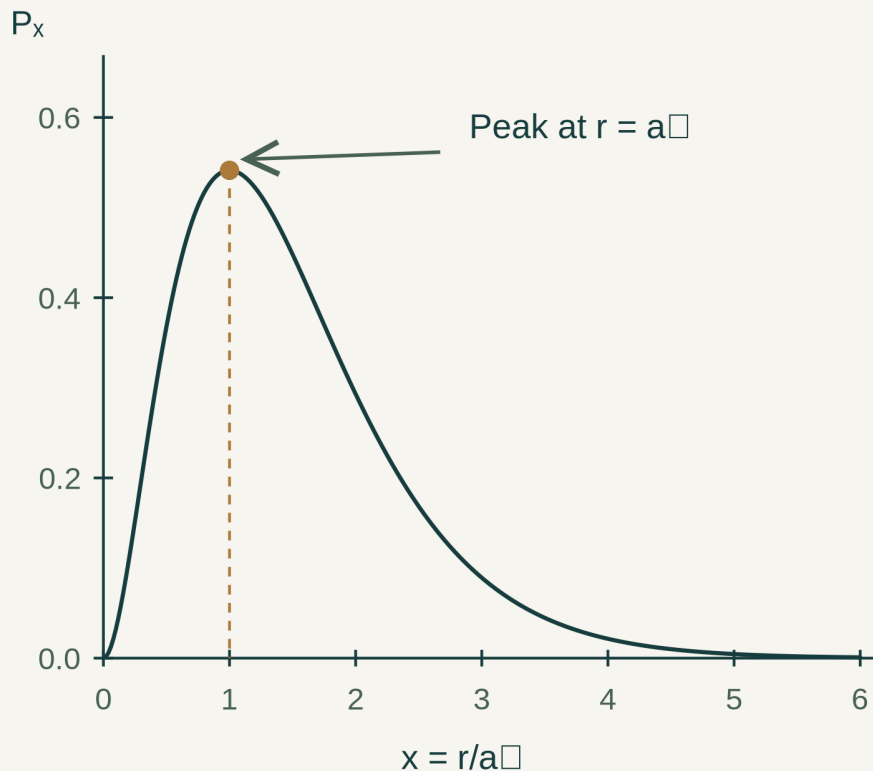
The normalized radial probability is $P(r)=4r^2\exp(-2r/a_*)/a_*^3$. It includes the volume of a spherical shell. Its peak is at $r=a_*$, whereas the probability density per unit volume is largest at the origin. Its mean radius is $3a_*/2$, so even the peak and mean describe different statistics.

The real stationary $1s$ wavefunction has zero probability current. This does not imply zero momentum variance. A broad stationary state can have vanishing mean momentum and nonzero mean squared momentum. The radial plot therefore describes repeated position statistics, not an electron tracing a circular path. Interpret every claimed source prediction using the same specific observable.

The Coulomb ground-state radial profile

$$x = r/a_0; P_x(x) = 4x^2 \exp(-2x)$$

$P_x(x) dx$ is probability in a spherical shell.



$$\int_0^\infty P_x(x) dx = 1$$

$$a_0 = \hbar^2/(\mu\kappa)$$

A radial probability, not a wave amplitude.

The Coulomb ground-state radial profile. Exact dimensionless radial probability for the nonrelativistic Coulomb 1s state. The factor x^2 is the spherical-shell measure; the spatial probability density and the wave amplitude have different shapes.

Open the full-size diagram →

Derive the speed statistic carefully

For a Coulomb bound state the virial relation is $2\langle T \rangle = -\langle V \rangle$, so $E = -\langle T \rangle$. The spectrum $E_n = -\mu c^2 g^2 / (2n^2)$ then gives $\langle p^2 \rangle = \mu^2 c^2 g^2 / n^2$. The relative RMS speed is $\sqrt{\langle p^2 \rangle} / \mu = cg/n$. In the ground state and after electromagnetic matching, $v_{\text{rel,rms}}/c = \alpha$.

In the centre-of-mass frame the electron carries the same relative momentum p but its velocity is p/m_e . Its RMS ratio is therefore $(\mu/m_e)g/n$. For an equal-mass pair, each constituent has half the

relative RMS speed. Only an infinitely heavy nucleus makes the electron and relative ratios coincide exactly.

Use several linked atomic checks

The same input g gives $a_* = \hbar/(\mu c g)$, ground binding magnitude $\mu c^2 g^2/2$ and relative RMS speed cg . At fixed coupling, changing nuclear mass alters μ , so radius scales inversely with μ , energy directly with μ and relative RMS speed remains unchanged. The electron centre-of-mass speed still changes through μ/m_e .

A source-derived matter law should reproduce these relations with one common clock and action dictionary. It should identify additional corrections before comparing precision spectra; the present model omits relativistic, spin, radiative and nuclear effects. Lesson 11 asks what could fix g upstream. Producing a structural integer is one candidate ingredient, while the normalized physical response remains an independent calculation.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

With $D=2$ and $C=4$, find a^* , E^* and $E(a)$ at $a=2$. How far is that energy above the minimum?

Exercise 2

For an illustrative nucleus $M=9m_e$ and $g=1/100$, calculate the ground-state relative and electron centre-of-mass RMS speed ratios. What is the mean velocity vector of the real $1s$ state?

Scope of this guide Exact relations within the supplied nonrelativistic Coulomb Hamiltonian. Coupling selection, physical matching and higher-order atomic corrections are separate obligations.

Continue with the articles

- A normalizable hydrogen-like ground state

Introduce the lower-bound and bound-state results of the effective model. Explain how the supplied kinetic and potential rules produce a meaningful atomic test case.

- Why binding does not fix the coupling

Introduce the dilation argument showing that a family of positive couplings remains compatible with binding and completion. Identify the extra source-selection law needed to obtain a specific interaction strength.

- Hydrogen and deuterium as complementary probes

A proposed isotope-comparison article within the differential-test program. Identify which effects are shared and which require separate mass and nuclear inputs before interpreting a residual.

Lesson 11: What 137 counts and what fixes a coupling

A count can be exact without being an interaction strength. This lesson follows the proposed structural integer to the separate response calculation that a physical coupling needs.

<https://www.smonad.com/learn/11-constants-and-137.html>

The central connection

The selected free grammar yields 137 distinguishable records. Obtaining an ideal inverse-rank coupling also requires a normalized response and a common action-clock dictionary.

What you will learn

- Calculate the branch ranks and continuation recurrence.
- Explain how record loss changes the free count.
- Compute a simple response capacity and distinguish it from receiver dimension.

Before you begin: Lessons 01–10. You should understand a record count, a probability and a supplied Coulomb coupling as different quantities.

Define the records before counting them

At depth d , choose d independent innovation labels and retain every nonempty subset. Each label may be present or absent, producing 2^d subsets before the empty one is removed. The branch ranks are therefore $b_d = 2^d - 1$. At depths one, two and three the counts are one, three and seven.

An exterior-algebra realization uses alternating products of distinct innovations; repeated labels vanish. That supplies a precise grammar, not a probability distribution over branches. The three algebraic depths are also distinct from the six nested inner roles introduced earlier. A source theory must connect these choices through its actual architecture rather than treating similar small integers as interchangeable descriptions.

Worked example: trace every contribution to 137

Supply a receiver with ten independent continuation labels. At depth d a record either terminates with one of b_d branches or attaches one continuation label to a previous-depth record. Keep these alternatives and combinations distinct. Starting with $r_0 = 0$ gives $r_d = 10r_{d-1} + b_d$.

$$r_1 = 1; \quad r_2 = 10 + 3 = 13; \quad r_3 = 130 + 7 = 137.$$

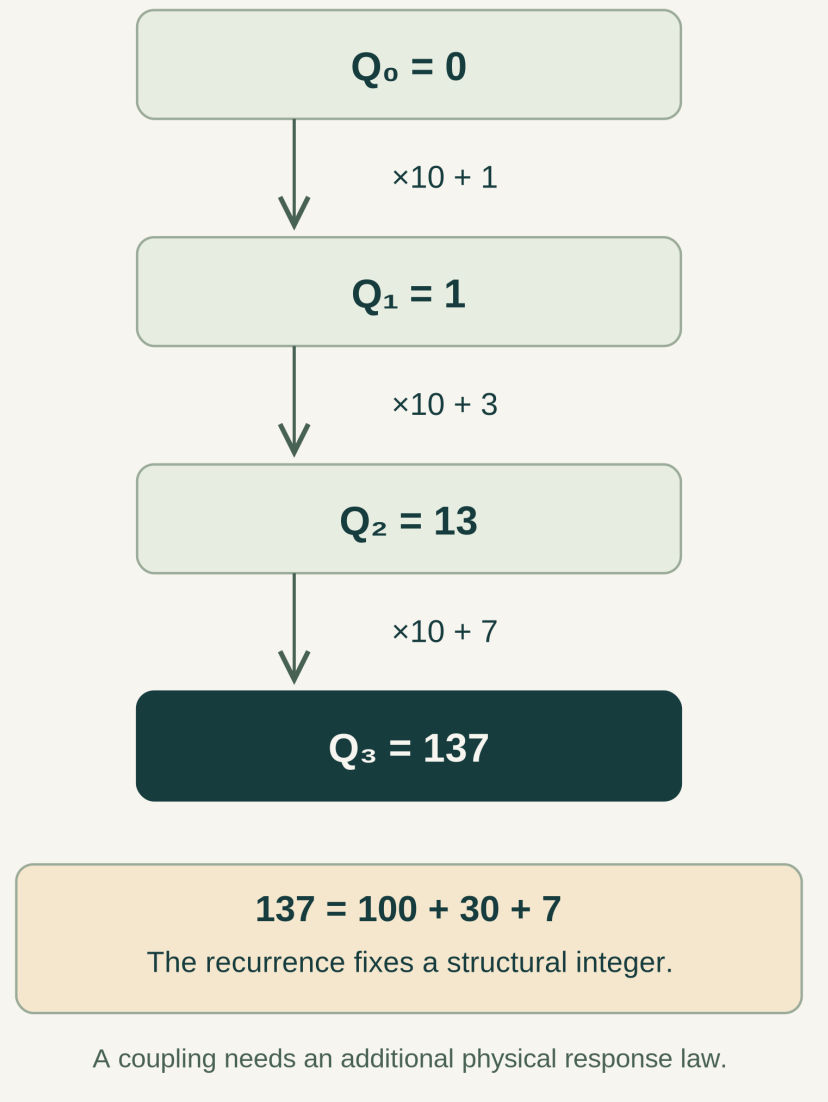
The final sectors have sizes 100, 30 and seven: two continuations before a depth-one terminal, one continuation before a depth-two terminal, or immediate depth-three termination. Distinct continuation and terminal tags make the words uniquely readable. The ten-mode receiver can

itself be selected as symmetric quadratic combinations of a four-component envelope, with count $4 \times 5/2 = 10$; selecting that receiver is substantive input.

The structural sequence $0 \rightarrow 1 \rightarrow 13 \rightarrow 137$

$$Q_0 = 0; Q_n = 10 Q_{n-1} + (2^n - 1)$$

Radix 10; increments 1, 3, 7 for $n = 1, 2, 3$



The structural sequence $0 \rightarrow 1 \rightarrow 13 \rightarrow 137$. Exact arithmetic for the stated radix-ten recurrence and subset-count increments. The result is a structural integer; identifying its reciprocal with an ideal coupling requires a separately normalized physical observable.

Open the full-size diagram $\rightarrow$

Faithful storage and probability are separate

If each legal word must be distinguished without error in a single quantum readout, their encoded pure states must be orthogonal. The declared task therefore needs at least 137 dimensions, and the free word basis attains that count. Allowing errors, asking fewer questions or using additional sequential resources changes the task and its minimum.

The count does not enforce equal final probabilities. An explicitly uniform sampler assigns $1/137$ to each word; locally uniform decisions generally give another law. Nor does a lossy implementation retain the free count automatically. If one independent combination disappears at depth two, each of the ten later continuation labels loses that possibility, so the final count becomes $137 - 10 = 127$.

The same dimension can respond differently

Let a positive response operator K assign energetic cost to receiver amplitudes and let f be a fixed source direction. Minimizing quadratic energy subject to a prescribed source reading gives capacity $C_{\text{resp}} = \langle f, K^{-1}f \rangle$. The inverse operator and source weights, not dimension alone, determine this number.

For two real modes, take $f = (1, 1)$ and $K = \text{diag}(2, 4)$. Then $K^{-1}f = (1/2, 1/4)$, so the capacity is $3/4$. Doubling K leaves two modes but halves capacity to $3/8$. The same logic applies to 137 records: stiffnesses $\kappa_1, \kappa_2, \kappa_3$ on the sectors give capacity $100/\kappa_1 + 30/\kappa_2 + 7/\kappa_3$. Equal rank does not imply equal response.

Locate the physical normalization

Under ordinary trace coupling and a particular continuum matching, the proposed dimensionless coupling has the form $g_N = s_{\text{cont}} / (4\pi acN)$. Here a is an action scale, c a propagation scale and s_{cont} the effective continuum stiffness. Both s_{cont} and ac have dimensions of energy times length.

With $N=137$, obtaining the ideal value $g_N = 1/137$ requires $s_{\text{cont}} = 4\pi ac$ as an additional physical relation. Since their ratio is dimensionless, changing units cannot impose it. The source must independently identify the current, derive response normalization and use the same action and clock dictionary as the matter dynamics. Only then can the resulting g be compared with the coupling entering Lesson 10's Hamiltonian.

Keep the exact result and its next bridge visible

The exact structural result is useful: a transparent selected grammar has 137 freely retained records. A proposed ideal inverse-rank value belongs to that model after further normalization. It is not automatically the measured inverse fine-structure constant, a running coupling at another energy or a prediction of uncalculated corrections.

To improve the argument, derive the grammar, stiffnesses and matter propagation from one source, then freeze their parameters before an additional measurement is predicted. The full structural derivation also separates dimension from determinant phase weight. The response guide derives the constrained minimization. Lesson 12 combines these distinctions into an evaluation of what a source model actually predicts.

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

Replace the ten continuation labels by eight while keeping branch ranks one, three and seven. Calculate r_1 , r_2 and r_3 .

Exercise 2

For $N=137$, let sector stiffnesses be $(2\kappa, \kappa, \kappa)$. Find the capacity and compare it with equal stiffness κ in every sector.

Scope of this guide Exact counting for the selected free grammar and finite positive-response examples. The structural integer is separate from empirical alpha, running couplings and the additional common-source normalization law.

Continue with the articles

- From three-dimensional readout to retained records

Trace the latest draft's route from quaternionic readout to a selected grammar with 137 distinguishable records. Keep each structural choice visible in the explanation.

- Why a record count is not yet a coupling

Explain why the static response depends on the source and inverse response operator, not simply on the number of records. This is the central bridge required by the coupling proposal.

- The conditional ideal value one over 137

Summarize the extra normalization and electromagnetic matching needed for the ideal model coupling. Explain why the draft's alpha-zero notation does not denote the measured low-energy constant.

- Why the symmetric receiver has ten modes

Count the independent symmetric quadratic combinations of a four-component envelope. Explain the receiver interpretation and why selecting that construction is a substantive modeling choice.

- Alternating branches and the ranks one, three, seven

Explain how positive-degree exterior sectors produce the branch counts used by the reconstruction. Keep the counting argument separate from any identification with particle families.

- Prediction after calibration

Present the calibration-fiber criterion for a conditional prediction. An additional observable must be fixed across the allowed calibrated models to avoid merely reusing its target value.

Lesson 12: Decide what a source model predicts

A good evaluation preserves exact achievements and asks precise questions at the remaining interfaces. Finish by testing whether one source model constrains several independent observations together.

<https://www.smonad.com/learn/12-evaluating-a-source-model.html>

The central connection

A prediction becomes informative when fixed assumptions and independently calibrated parameters restrict a new observable across every remaining admissible model.

What you will learn

- Separate proved statements, supplied inputs and physical interpretations.
- Test whether calibration leaves a target observable undetermined.
- Design an overconstrained comparison with fixed parameters and explicit alternatives.

Before you begin: Lessons 01–11. This final lesson uses the record, geometry, phase, clock, gauge, matter and response distinctions developed throughout the course.

Attach a claim to its actual premises

For each result, write its input, calculation and output. The binary counter begins with a signed paired readout and yields 27 sites. Polar phase selection begins with an oriented invertible skew generator and yields $J^2 = -I$. The Coulomb calculation begins with a Hamiltonian and yields a bound state. These are positive exact results, each with a different dependency.

Next identify the proposed physical interpretation. Calling the sites space, the phase a material clock or the bound state hydrogen requires operational matching. The research claim map and model-consistency guide organize these checks. A missing interface does not erase an earlier theorem; it tells us which additional construction would extend its explanatory reach.

Worked example: one calibration leaves freedom

Suppose a model has parameters a and b . A calibration fixes $a+b=3$, while the target output is $Y=a-b$. Two allowed choices, $(a,b)=(2,1)$ and $(1,2)$, satisfy the same calibration but give $Y=1$ and $Y=-1$. Therefore the calibration alone does not predict Y .

The set of parameter choices satisfying the calibration is the remaining calibrated family. A target is fixed only when it has the same value across that whole family, within declared errors. A source law imposing $b=a/2$ would reduce the example to $a=2, b=1$ and predict $Y=1$. But fitting $b=a/2$ after measuring $Y=1$ would reuse the target. The order in which information enters matters to the evidential claim.

Use an alternative that obeys the same early results

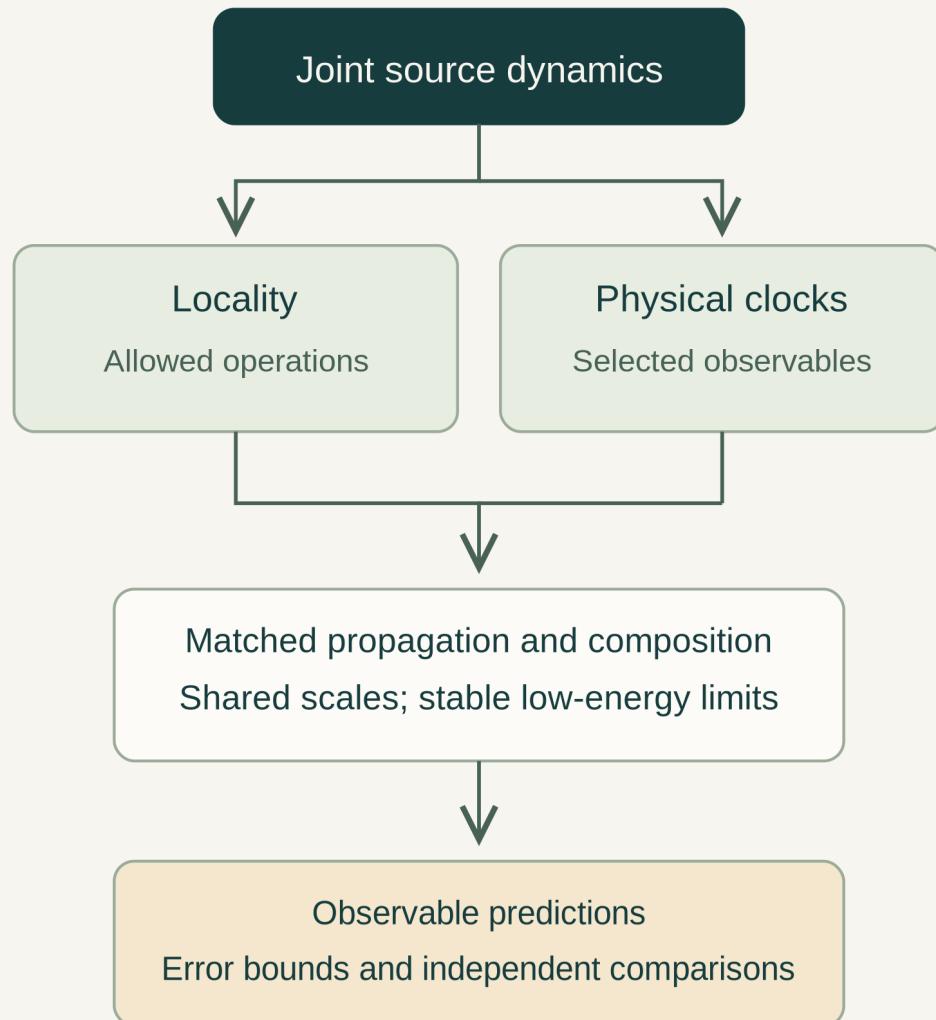
Consider a refinement construction with record dimension D and an inner quantity $u=D\tau$. A proposed clock reads $T=\tau$, giving $u/T=D$. An alternative clock can read $T=\tau+\lambda u$ while preserving the same record count and inner relation. Then $u/T=D/(1+\lambda D)$.

For $D=2$ and $D=3$, $\lambda=0$ gives two and three, whereas $\lambda=1$ gives $2/3$ and $3/4$. No single fixed rescaling makes the two clock laws agree across both settings. This countermodel identifies a meaningful selection question: what source interaction excludes or fixes λ ? Merely naming one device the outer clock cannot establish universal clock response. A useful theorem constrains the competing interaction through independently justified source dynamics.

A connected programme of open problems

One source; several compatible physical limits.

Arrows show research dependencies, not completed proofs.



Conceptual research-dependency map. **A connected programme of open problems.** A proposed order of research obligations. A success at one node does not establish the next; each arrow requires explicit assumptions and a mathematical or operational construction.

Open the full-size diagram →

Use the demonstrations as six separate checks

The nested-generation demo tests dependency and address counts. The binary readout tests multiplicity and lost carry memory. The phase rotation tests the quarter-turn algebra. The clock comparison tests a supplied relativistic benchmark.

The gauge loop tests endpoint cancellation, while the binding curve tests the supplied Coulomb energy family. Reproducing each default is a consistency check. The common-source challenge is

to derive a shared restriction connecting their inputs, so one calibrated output fixes another. Six individually correct demonstrations do not automatically form one autonomous physical model with a shared memory, clock and action scale.

Read published results at their own level

The published completion framework organizes observable quotients, compatible phase structures and conditional cone readouts. The real-commutant paper treats phase selection for real Hilbert representations. The temporal-asymmetry paper uses coupled temporal coordinates and projected memory descriptions. Their paper guides help locate assumptions and follow the original sources.

The later nested-counter constructions are not automatically identical to the published two-coordinate formulation. An explicit translation must identify state spaces, operations, observables and completion. Nor do the three papers by themselves establish every receiver grammar, gauge group, Pauli law, Einstein equation or Yang-Mills gap discussed elsewhere in the programme. Evaluate each claimed bridge through the particular result and hypotheses that support it.

Design a comparison that can change your conclusion

Choose an accessible target and an alternative model before looking at the target result. Calibrate only the allowed parameters, freeze them, then predict several settings with the same values. Include failed or incomplete outcomes, apparatus uncertainty and memory preparation. A residual is interpretable only after ordinary responses covered by the comparison model are accounted for.

For an atomic example, use one coupling and reduced-mass dictionary to predict radius, binding energy and momentum relations together, then declare which corrections are included. For a memory example, fit one response protocol and predict another without changing the kernel. The prediction guide develops this workflow. The course's final question is concrete: which new relation does the common source enforce that its explicit alternatives do not?

Try the exercises

Work through each question, then open the answer to compare the steps.

Exercise 1

A calibration fixes $ab=6$ for positive parameters. The target is $a+b$. Compare $(a,b)=(2,3)$ and $(1,6)$. Has the target been predicted?

Exercise 2

A source model is fitted to one hydrogen radius and then reports that same radius as a success. It also gives a ground binding energy from the fixed parameters. Classify the two outputs and state a fair next check.

Scope of this guide Course synthesis and explicit countermodel arithmetic. Publication descriptions identify modular scopes; the lesson does not claim empirical discrimination, a new experiment or a completed universal source theory.

Continue with the articles

- Prediction after calibration

Present the calibration-fiber criterion for a conditional prediction. An additional observable must be fixed across the allowed calibrated models to avoid merely reusing its target value.

- Why one clock model does not prove universality

Use the ungated-clock countermodel to show that a realizable clock law need not be physically universal. Explain the extra selection principle required for all material clocks to agree.

- Six inner stages and one publication interface

Explain the hierarchy of readout ranks 1, 1, 2, 2, 3, 3 followed by completion. These are nested functional roles rather than six independently readable temporal coordinates.

- Freeze parameters before predicting spectroscopy

Explain the post-freeze strategy proposed for atomic observables. A spectroscopy comparison becomes informative when its coefficients are fixed without using the same transitions as targets.

- Designing an overconstrained atomic test

Turn the skeleton draft's research direction into a practical analysis plan. Require more independent observables than fitted parameters and predeclare the cross-state prediction rules.

- Real-commutant phase selection: a paper guide

Introduce the paper's phase-selection question in real Hilbert representations. Prepare an accessible route from the commutant to compatible complex structures and their physical interpretation.

- Temporal asymmetry: reading the published model

A reading guide to the published temporal-asymmetry model. Organize its geometrical assumptions, reduction mechanism, and interpretation before comparing it with later working drafts.

Sources and reading

- Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations
- Real-commutant phase selection from real Hilbert representations
- Dual-Time Topological Geometry and the Emergence of Temporal Asymmetry in Non-Equilibrium Dynamics

Worked answers

Compare the reasoning, not only the final number.

The following answers preserve the complete solution text from each lesson. An example based on selected assumptions illustrates a calculation; it does not establish those assumptions as physical laws.

Lesson 01

Exercise 1

The four histories are AA, AB, BA and BB because $2^2=4$. AA has zero B operations and BB has two, so both are even. AB and BA each have one B and are odd. Under uniform preparation each history has probability $1/4$; each class therefore has probability $2/4=1/2$. There remain two possible records even though the history count has fallen from eight to four.

Exercise 2

The records are A and B, so there are two. Four histories end in each letter. AAB and BAB both end in B, so this detector identifies them. A detector of the first letter separates them, reporting A and B respectively. The distinction is therefore relative to the chosen observation rule; it is not determined by the fact that there is one source.

Lesson 02

Exercise 1

Role two uses $3^2=9$ addresses and the first pair gives rank one. Role five uses $3^5=243$ addresses and has opened the third direction, so rank three. Role seven publishes all six digits: $3^6=729$ addresses and rank three. It adds a completion status, not a seventh digit, so 3^7 is not the relevant count.

Exercise 2

With fresh, independent retries and complete recovery, the attempt count has probabilities $(1/2)^n$ for $n=1,2,\dots$ and mean $1/p=2$. Each attempt visits eight addresses, giving expected visits $8 \times 2=16$. A successful-episode counter advances once. Converting these counts to duration still requires a measured cost per visit and any reset or verification time.

Lesson 03

Exercise 1

Both preparations display $x=1$. The first next display is $3 \times 1 + 2 \times 0=3$; the second is $3 \times 1 + 2 \times 4=11$. A function of the common input one cannot give both three and eleven. The difference eight equals $b\Delta y=2 \times 4$. Retaining y , or forbidding this coupling, is necessary for an exact first-order reduced prediction.

Exercise 2

Apply the rule twice: (x,y) becomes $(-y,x)$, then $(-x,-y)$. The first component after one step depends on hidden y . After two steps it is $-x$, which depends only on retained x . Thus the two-step completed update closes as $V(x)=-x$ even though the individual step does not. Its use requires that both steps have actually completed.

Lesson 04

Exercise 1

The first coordinate has one representative, the second has two, and the third has one. Independence gives $M=1 \times 2 \times 1=2$. Since each of the 64 addresses has probability $1/64$, the site's probability is $2/64=1/32$. It belongs to the class with two nonzero coordinates; there are twelve such sites, together carrying probability $12/32=3/8$.

Exercise 2

The differences $-2, -1, 0, 1, 2$ have respectively 1, 2, 3, 2, 1 representatives. The total is nine, as required for two ternary digits. Three pairs therefore give $5^3=125$ sites from $3^6=729$ addresses. The origin has $3^3=27$ representatives, so its probability is $27/729=1/27$ under uniform address sampling. The rank remains three.

Lesson 05

Exercise 1

The indirect path still costs $2+3=5$, while the direct path now costs four, so $d(A,C)=4$. Choose $f(A)=0$, $f(B)=2$ and $f(C)=4$. The three differences are two, two and four, bounded by edge costs two, three and four. This reading attains the new distance and verifies that the shortcut changes the operational metric.

Exercise 2

Fewer than five episodes cannot connect the disturbance to the detector under the declared support bound. The earliest permitted time is therefore $5 \times 3=15$ clock units, over graph length $5 \times 2=10$. The maximum slope is $10/15=2/3$ length units per clock unit. This is a lower bound on arrival time, not a guarantee that any signal actually reaches the detector at that time.

Lesson 06

Exercise 1

Squaring gives $-A^2=\text{diag}(4I, 25I)$, so $\Omega=\text{diag}(2I, 5I)$. Multiplication by its inverse yields $J=\text{diag}(J_0, -J_0)$, and $J^2=-I$ on both planes. With i represented by $-J$, $iaA=(-J)aJ\Omega=a\Omega=H$. Both energy blocks are positive for $a>0$ even though the original plane rotations have opposite orientations.

Exercise 2

$J^2(x,y)=(-x,-y)$, whereas $S^2(x,y)=(x,y)$. Thus J represents an ordinary complex unit and S a split-complex unit. The latter exponential maps x to $x \cosh \eta + y \sinh \eta$ and y to $x \sinh \eta + y \cosh \eta$. Expanding $x'^2 - y'^2$ cancels the cross terms and gives $(\cosh^2 \eta - \sinh^2 \eta)(x^2 - y^2) = x^2 - y^2$.

Lesson 07

Exercise 1

Two failures followed by success have probability $(3/4)^2(1/4)=9/64$. Failure on all three attempts has probability $(3/4)^3=27/64$, so success within three has probability $1-27/64=37/64$. The mean count over all possible attempts is $1/p=4$. This mean is not a guarantee of success by attempt four.

Exercise 2

The input density matrix is one half times the matrix whose four entries are one. Unread measurement sets its off-diagonal entries to zero, giving $I/2$. Conjugation by H gives $H(I/2)H^\dagger=I/2$ because $HH^\dagger=I$. The final zero probability is therefore $1/2$, whereas applying H directly to the coherent $|+\rangle$ would give zero with probability one. The missing coherence cannot be restored by that unitary alone.

Lesson 08

Exercise 1

The rate factor is $\sqrt{1-0.8^2}=\sqrt{0.36}=0.6$. Thus $\gamma=1/0.6=5/3$ and $\Delta\tau=12\times0.6=7.2$. A stationary ideal clock accumulates twelve, so the assigned duration difference is $12-7.2=4.8$ units. Directly received pulse rates need not show this factor without accounting for propagation.

Exercise 2

The rest segment contributes three and the moving segment contributes $5\sqrt{1-0.36}=4$. Total proper time is seven. At two cycles per proper-time unit the unwrapped phase count is fourteen cycles, or 28π radians. A circular display would return to its initial angle, so a retained cycle counter is required to recover the elapsed seven units.

Lesson 09

Exercise 1

Use arrival shift minus departure shift. The links become $10-5-5=0$, $20+10-(-5)=35$, $30+0-10=20$ and $40+5-0=45$ degrees. The transformed sum is $0+35+20+45=100$ degrees, equal to the original $10+20+30+40$. Every frame shift has cancelled once positively and once negatively.

Exercise 2

The probability is $(1+\cos 60^\circ)/2=(1+1/2)/2=3/4$. Since $\cos(-60^\circ)=\cos 60^\circ$, the same port probability occurs for the opposite phase. A second reference-phase setting sensitive to $\sin\Phi$ can distinguish the signs. This illustrates why one invariant response need not retain every distinction contained in the full complex holonomy.

Lesson 10

Exercise 1

The minimizing scale is $a^*=2D/C=4/4=1$ and the minimum is $E^*=-C^2/(4D)=-16/8=-2$. At $a=2$, $E=2/4-4/2=1/2-2=-3/2$. The energy lies $(-3/2)-(-2)=1/2$ above the minimum. Its dimensionless value is $(-3/2)/2=-3/4$, consistent with $x=2$ in the demonstration.

Exercise 2

The reduced-mass factor is $\mu/m_e=M/(m_e+M)=9/10$. Hence $v_{\text{rel,rms}}/c=1/100=0.01$ and $v_{\text{e,rms}}/c=(9/10)(1/100)=0.009$. The mean velocity vector and probability current are zero for the real stationary 1s state. Nonzero RMS speed refers to the positive momentum variance, not a nonzero mean vector or a sharply defined orbit.

Lesson 11

Exercise 1

The recurrence is now $r_d=8r_{(d-1)}+b_d$ with $r_0=0$. It gives $r_1=1$, $r_2=8\times1+3=11$ and $r_3=8\times11+7=95$. Expanding by terminal depth gives $8^2\times1+8\times3+7=64+24+7=95$. The changed answer makes the continuation receiver's role explicit; 137 does not follow from branch ranks alone.

Exercise 2

The capacity is $100/(2\kappa)+30/\kappa+7/\kappa=(50+30+7)/\kappa=87/\kappa$. Equal stiffness gives $(100+30+7)/\kappa=137/\kappa$. Both receivers have 137 states, but the first has capacity smaller by the factor $87/137$. Fixing the count therefore does not fix the physical response; one must also derive the stiffness assignment and source normalization.

Lesson 12

Exercise 1

Both pairs satisfy $ab=6$. Their target values are $2+3=5$ and $1+6=7$, so the calibrated family leaves the target undetermined. A further independently justified relation, such as $a=b$, would give $a=b=\sqrt{6}$ and target $2\sqrt{6}$. Imposing that relation because it fits the already observed target would not be an independent prediction.

Exercise 2

The fitted radius is a calibration output, so reproducing it checks implementation but supplies no independent predictive success. The binding energy is a conditional prediction if every coefficient and correction entering it was fixed without using that energy. A fair next check compares the frozen energy prediction with its independent target and stated uncertainty, then tests another transition or isotope using the same interaction law and separately supplied mass inputs.

Further reading and publication record

Three published reference points

These papers have different mathematical and physical scopes. Read the assumptions and conclusions in each original publication. Their appearance in this bibliography does not establish every later reconstruction described by the course.

Completion principles, real commutants, and positive-frequency geometry for orthogonal Hilbert representations

Mohamed Haj Yousef. Open Journal of Mathematical Sciences 10 (2026), 996–1012.

<https://doi.org/10.30538/oms2026.0328>

Real-commutant phase selection from real Hilbert representations

Mohamed Haj Yousef. Physics Letters A 594 (2026), Article 132085.

<https://doi.org/10.1016/j.physleta.2026.132085>

Dual-Time Topological Geometry and the Emergence of Temporal Asymmetry in Non-Equilibrium Dynamics

Mohamed Haj Yousef. Mathematics 14(5) (2026), Article 853.

<https://doi.org/10.3390/math14050853>

A reproducible reading habit

For each claim, record its inputs, equation, logical status, relevant source, and what would distinguish it from another model. Freeze fitted parameters before judging new comparisons. Keep dimensions, dimensionless ratios, probability laws, phase conventions and measured quantities separate.

Edition and source note

This is the coordinated print edition of the twelve existing English lessons, with their 24 exercises and full worked answers. The accompanying website package provides all twelve Arabic translations with reciprocal language links. The source figures are preserved from the site's existing SVG collection. No new rights or licence are assigned by inclusion in this handbook. Page layout changes do not change the scientific scope of the lessons.