"The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point." [Claude Shannon, 1948]

"Information has nothing to do with meaning" [Warren Weaver, 1949]

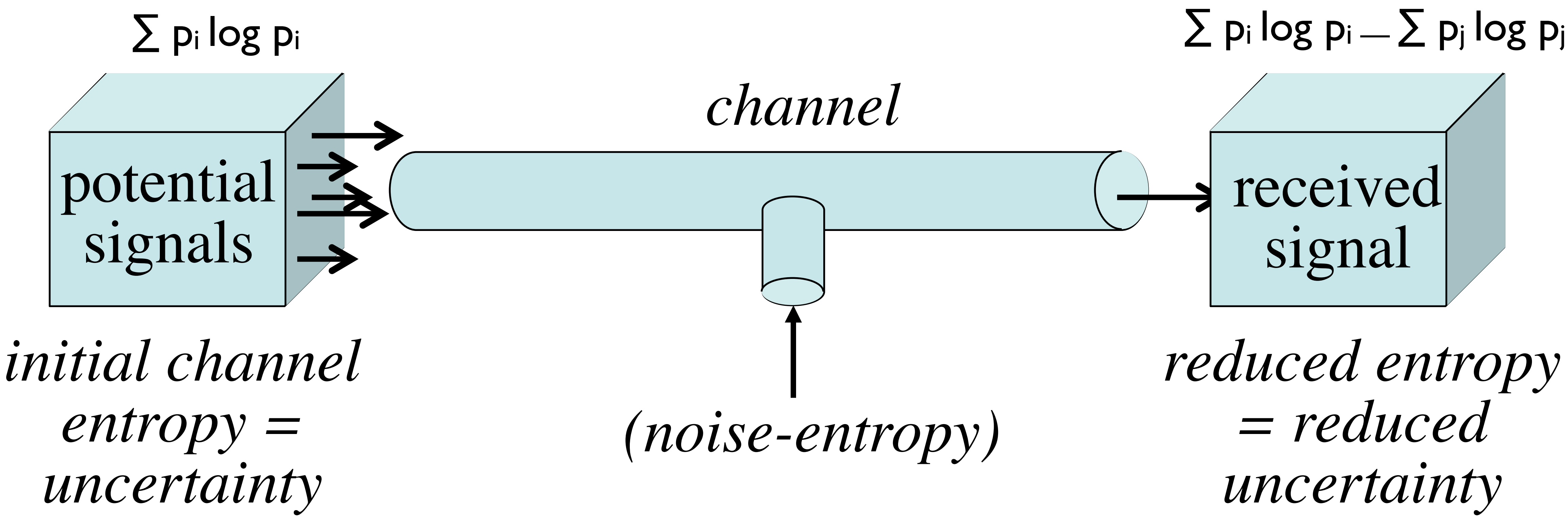
"The great tragedy of formal information theory is that its very expressive power is gained through abstraction away from the very thing that it has been designed to describe." [John Collier, 2003]

"…there is no general agreement about the relation between physics and information." [Werner Ebling, IS4IS 2015]

“I didn’t like the term Information Theory. Claude didn’t like it either. You see, the term ‘information theory’ suggests that it is a theory about information – but it’s not. It’s the transmission of information, not information. Lots of people just didn’t understand this... I coined the term ‘mutual information’ to avoid such nonsense: making the point that information is always about something. It is information provided by something, about something.” [Interview with R. Fano, 2001]

“What I have tried to do is to turn information theory upside down to make what the engineers call “redundancy” [coding syntax] but I call “pattern” into the primary phenomenon. . . . [Gregory Bateson, 1969]

Shannon's measure of information



- Shannon measured information in terms of the reduction in uncertainty that results from receiving a specific signal.
- The difference between possible signal entropy (a measure of its possible variant forms) and the entropy of the received message is the measure of reduced uncertainty.
- This reduction can be understood as a measure of *constraint* on possible degrees of freedom of the signal medium.

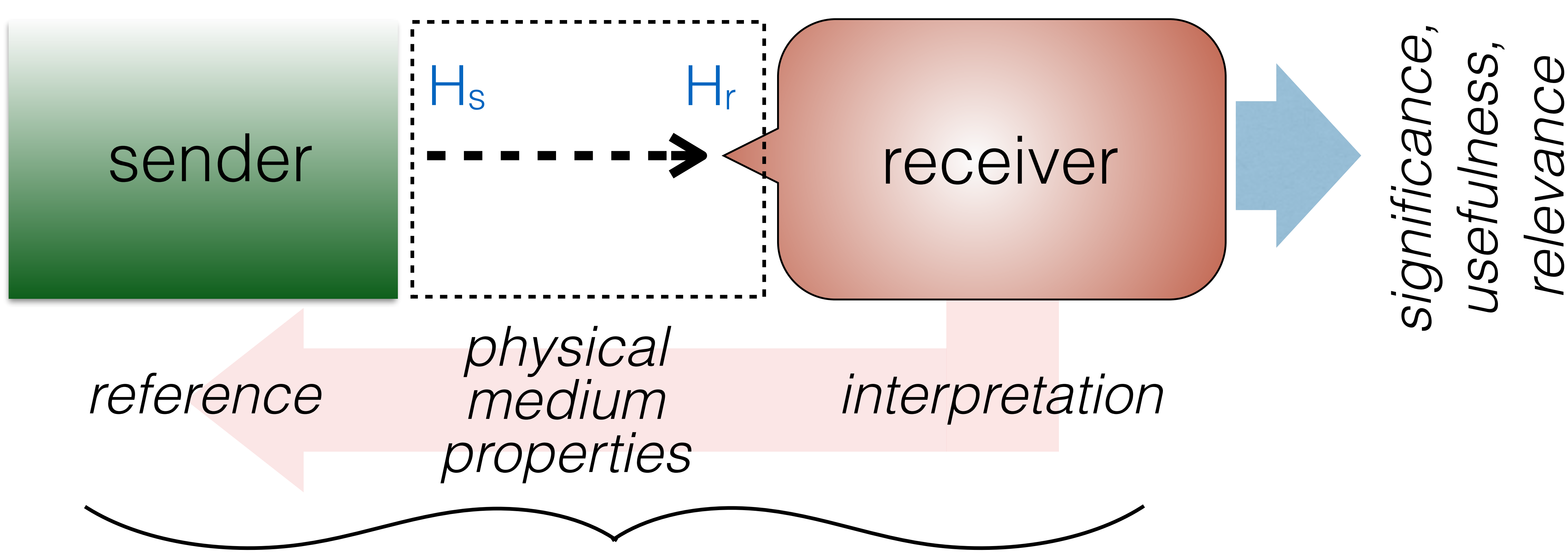
Properties analyzed by the mathematical theory of communication

Mutual information is a measure of the information redundancy between two systems (i.e. correspondence) It is not equivalent to reference or "meaning."

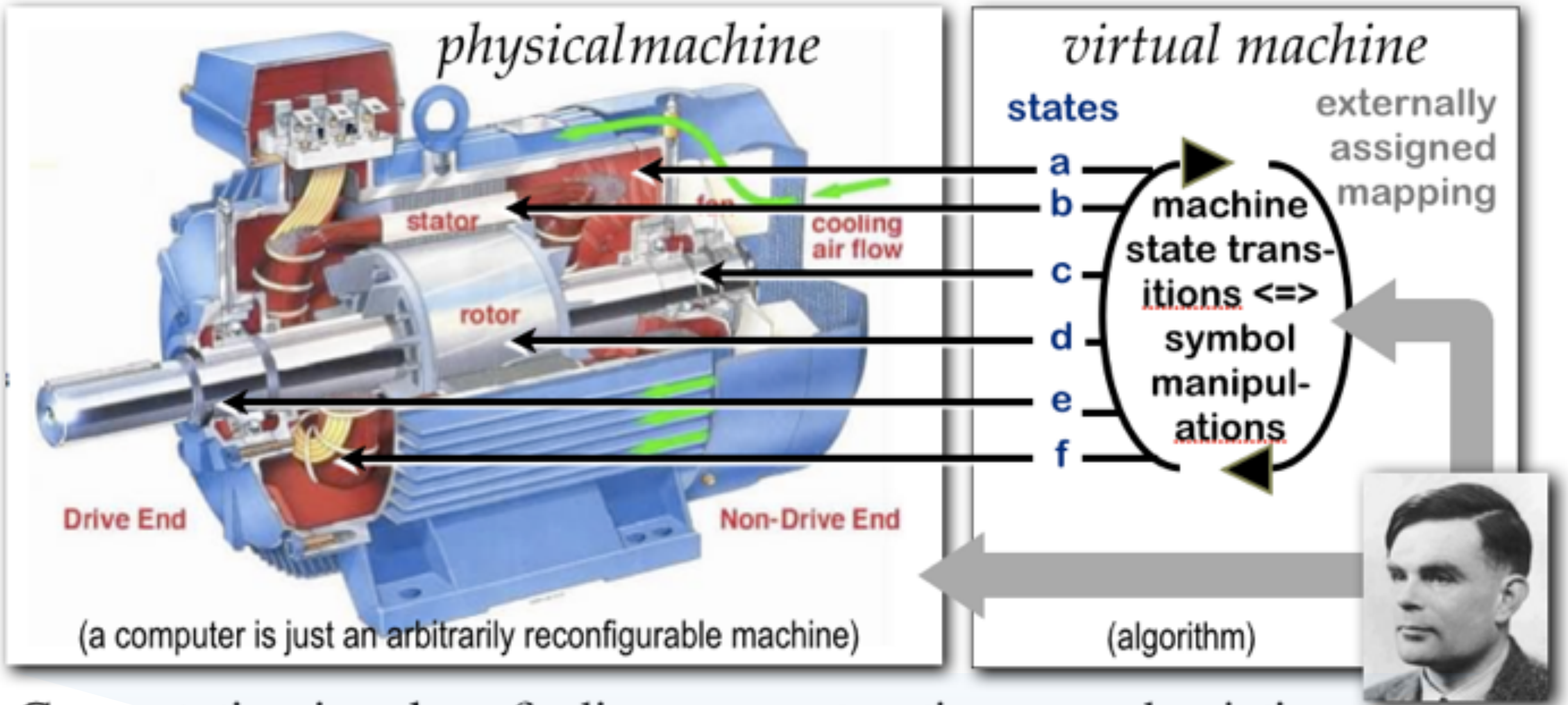
entropy= H_s H_r

transmitted information = $H_t = H_s - H_r$

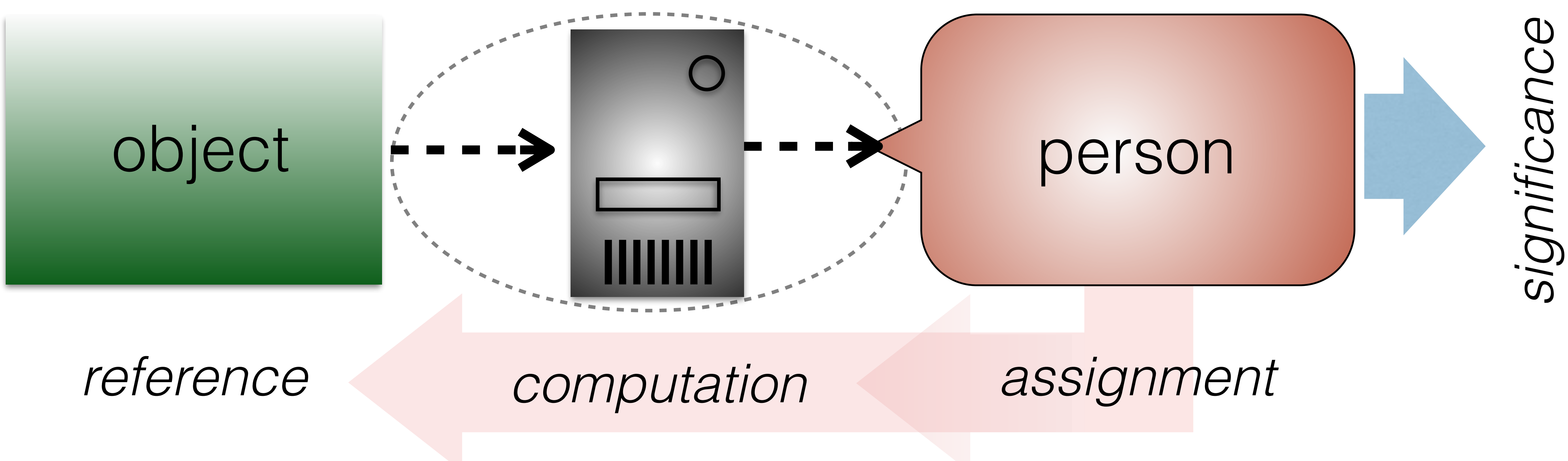
mutual information = $H_m < H_s + H_r$



relationships ignored by the mathematical theory of communication



Computation involves finding or constructing a mechanistic isomorphism with a formal operation, etc.



The difference between a computer and any mechanical device is a function of referential correspondences being ***extrinsically*** assigned.

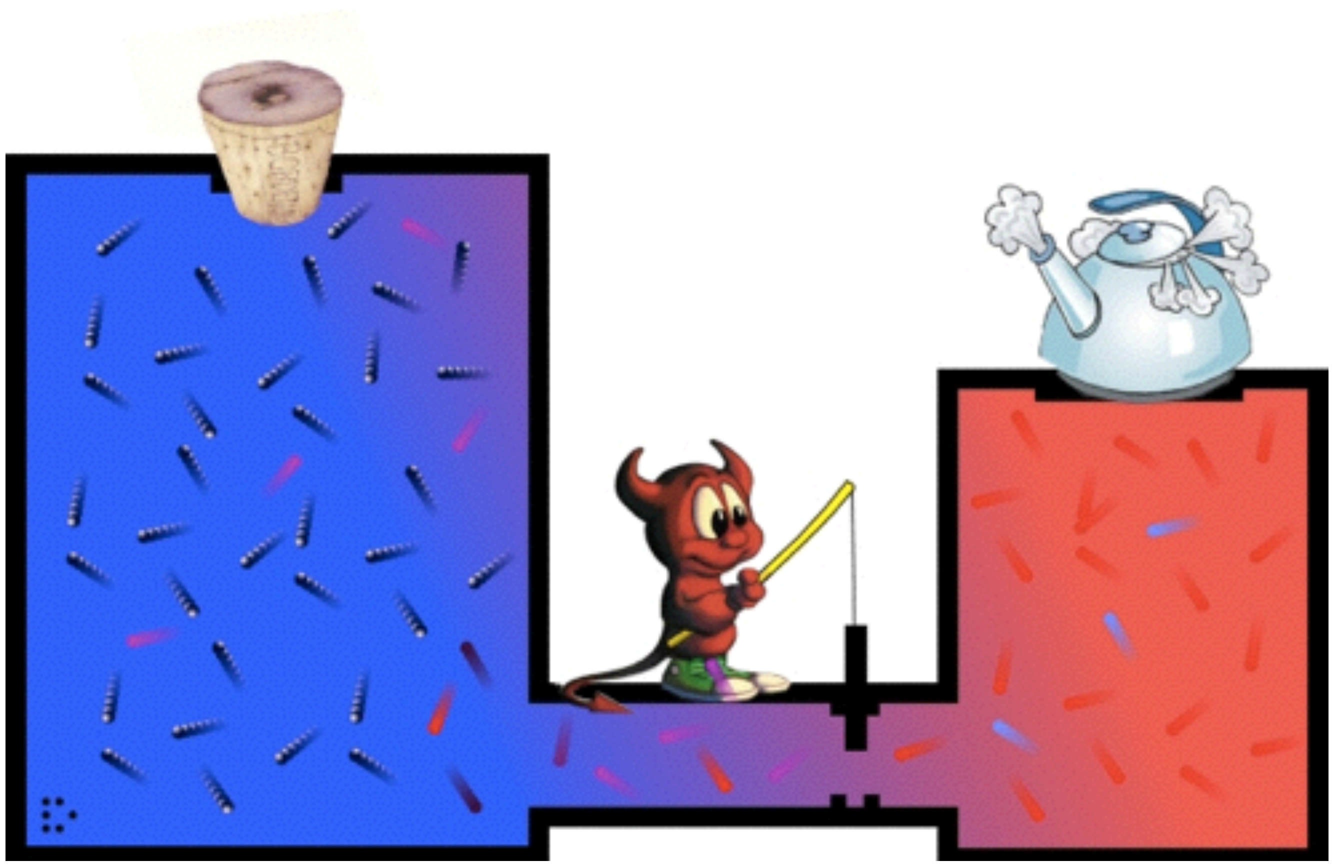
“Aboutness" is not intrinsic

- Information in the full sense is distinguished from other physical or statistical properties by virtue of providing ***reference (“aboutness") and relevance (i.e. functional significance, value).***
- These properties are ***not intrinsic*** to any specific physical substrate or signal medium, nor are they statistical attributes of the medium.
- What information is “about” is precisely something ***not*** present in the conveying medium.
- But if aboutness needs to be assigned extrinsically to computations it must not be a computable property

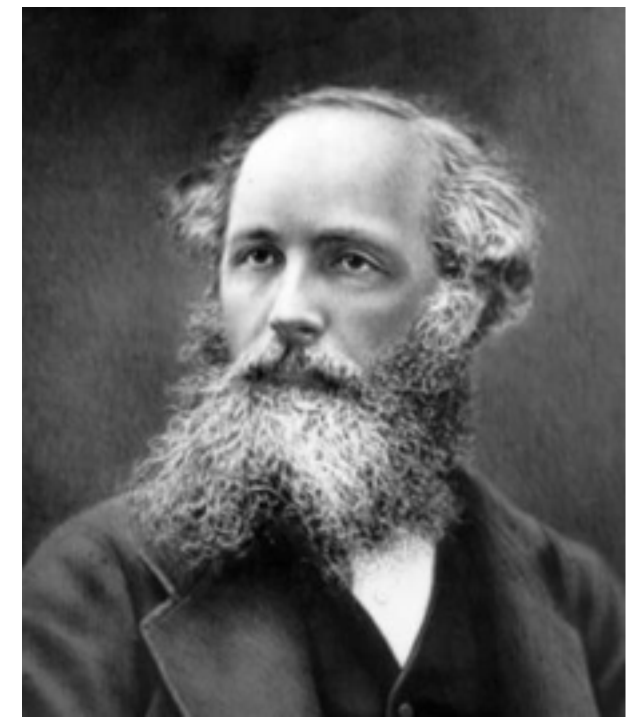
Nested levels of “information”

1.Shannon - 2.Boltzmann - 3.Darwin

Information ≠ thermodynamics, but



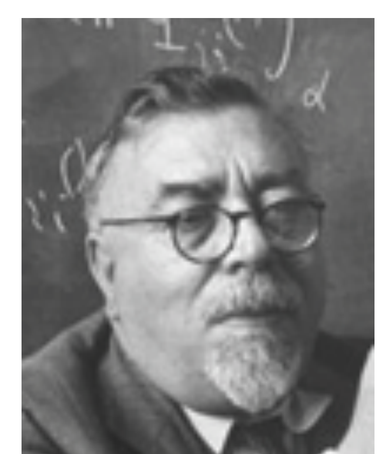
Maxwell's demon: a link between thought and entropy?



Information "entropy" and thermodynamic entropy are different uses of the same term & formula. Is this a confusion, or is there a deeper relationship between them (+/-)? And what about the properties of reference and significance? Are they illusory?

Schrödinger: information +negentropy → life

Shannon: information "entropy" $=\sum p_i \log p_i$

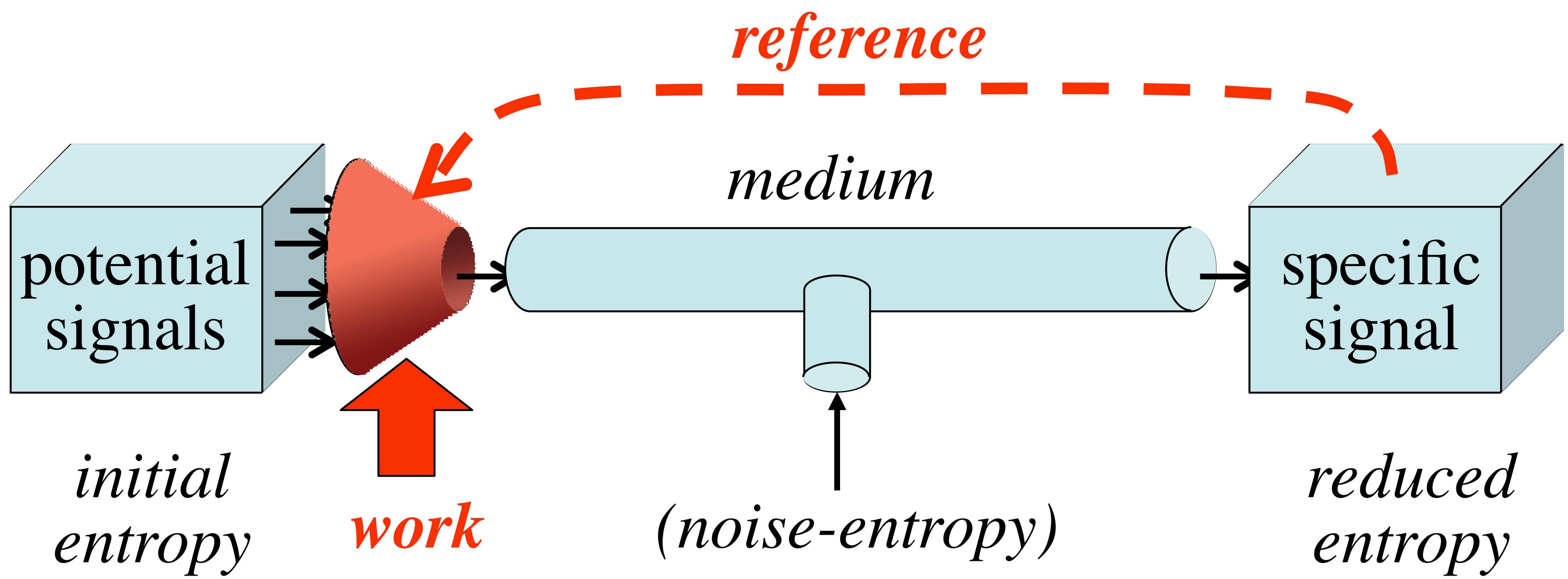


Wiener: "Information is negative entropy"

A tale of two entropies

- *"Information is physical."* — Charles Bennett
- Beyond their abstract statistical similarity, thermodynamic and informational entropy are associated with quite dissimilar processes and phenomena (e.g. the 2nd law of thermodynamics has no Shannonian counterpart).
- But since every informing medium is constituted physically - its informational states are physical states.
- So a change in that medium's statistical properties (e.g. its thermodynamic entropy) also has the potential of changing its informational properties.
- This is exemplified by the fact that thermodynamic effects can introduce "noise" into a message or can become information to a repairman..

Reduction of the Shannon entropy of a physical sign medium requires work



- Because Shannon entropy reduction employs a physical medium this also entails that its physical entropy is also reduced.
- This requires work and also entails thermodynamic openness.
- The pattern (constraint, redundancy) exhibited by the received signal with respect to the entropy of potential signals thus necessarily ***re-presents*** the constraints created by this work.

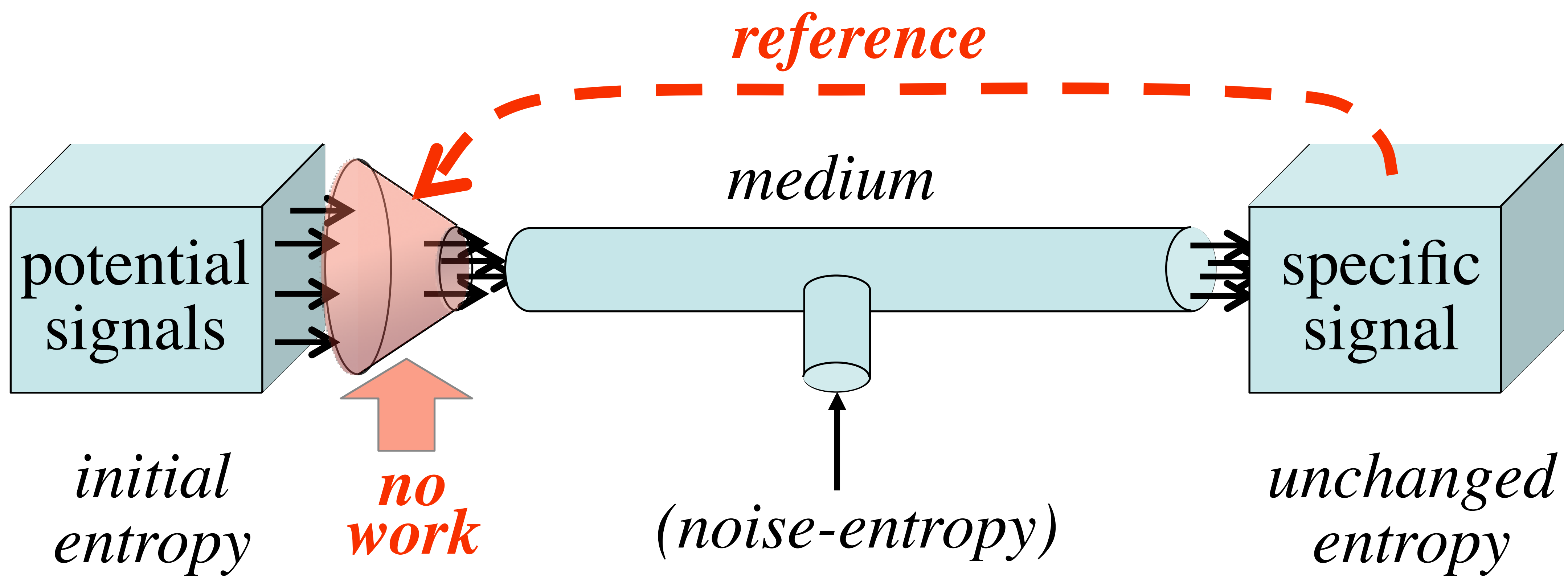
Improbable natural forms indicate the work of unusual geological forces

Stone circles (Iceland)

Basalt columns (Ireland)

Highly regular (constrained) geological forms are improbable. Thus they *indicate* the effects of prior work specifically capable of generating these constraints in contrast to the more common unorganized stone forms.

No change of information entropy ≠ lack of referential information

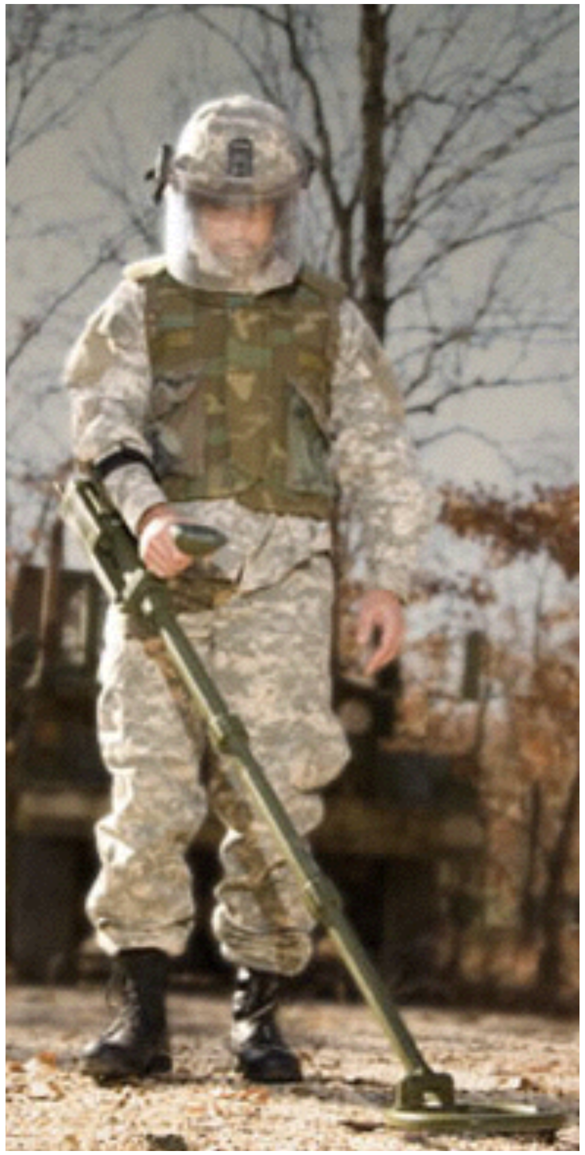


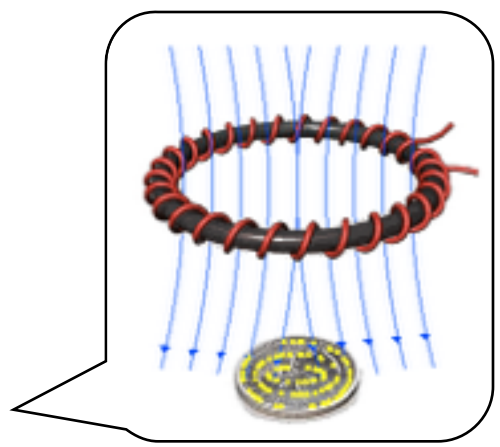
- Openness to the effects of the imposition of work and therefore to the propagation of constraint is the ground on which referential information depends.
- Zero message information = no change of signal entropy = no extrinsic work = <u>information about the absence of something</u>.

∴ Reference is a function of the ***potential*** for extrinsic influence.

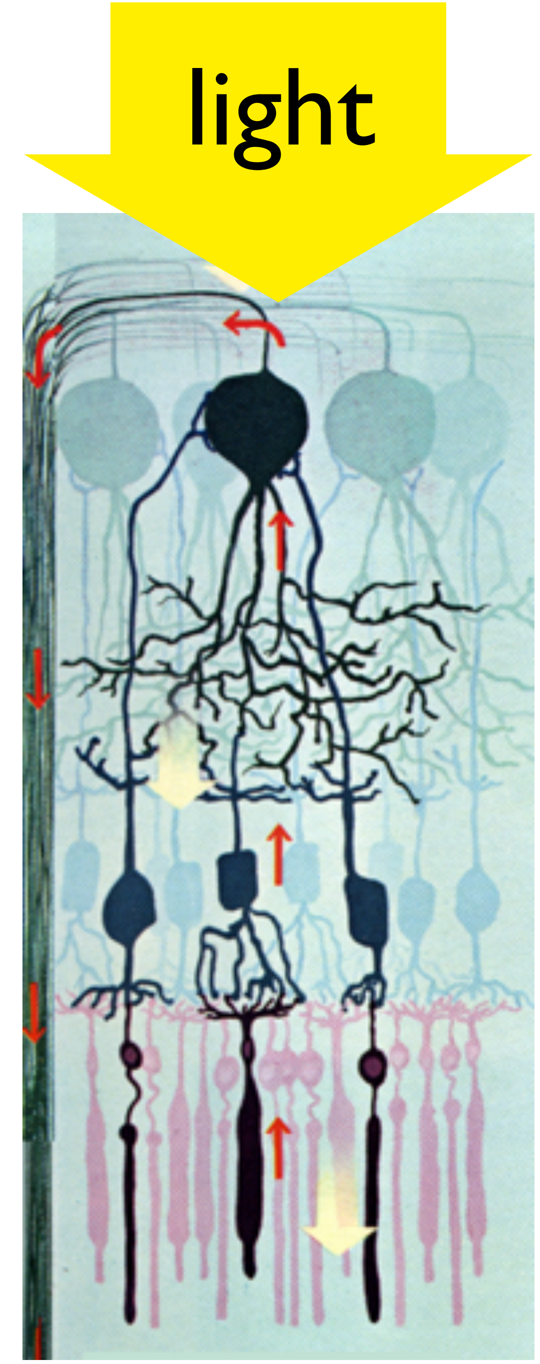
Far-from-equilibrium media

metal detector

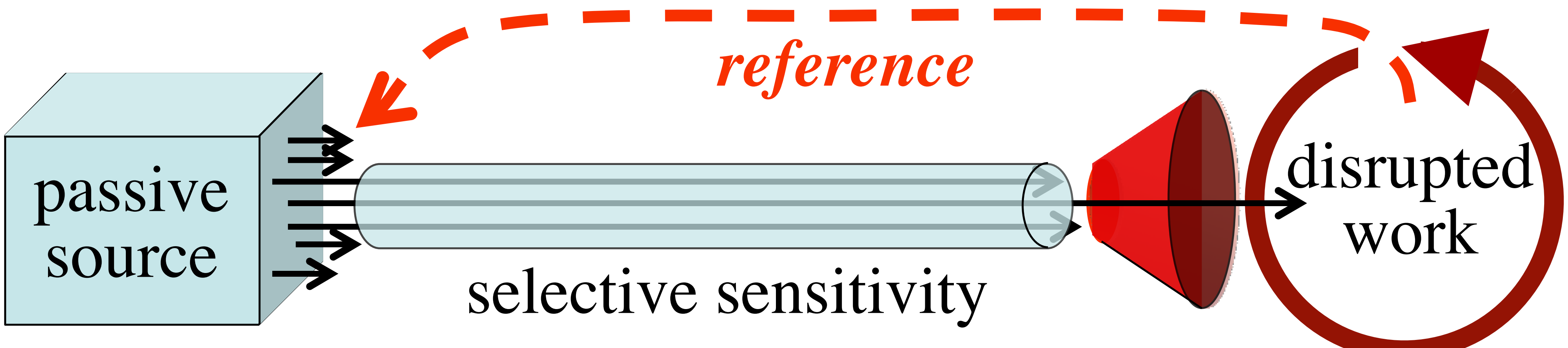




When work performed by a medium that is sensitive to specific external influences it can provide referent information about a specific class of objects relevant to that process.



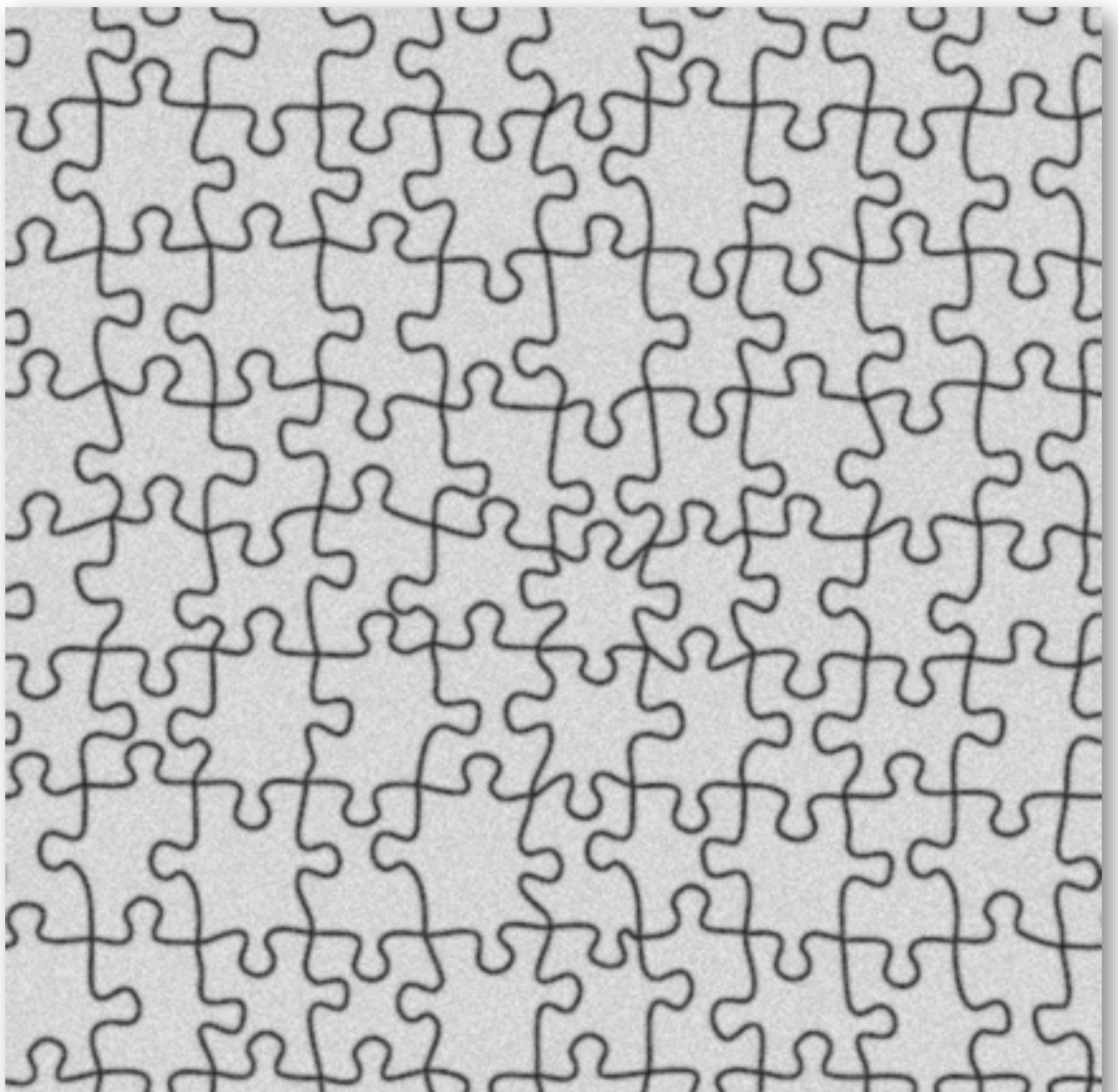
constantly active retinal neurons



Significance: work that saves work

- Living processes are organized around the problem of performing work to resist the increase of entropy.
- Work requires "the constrained release of energy" through a few degrees of freedom
- Resources must be obtained from the environment
- natural selection is in this respect a function of competition over work efficiency both intrinsically and in ability to efficiently utilize the environment.
- Information provides constraints that help reorganize the constraint-generating work of the organism.
- *Informational significance can be measured in* ***work saved*** *in achieving some functional end with respect to work needed to achieve it without that information*

Significance/usefulness = work saved



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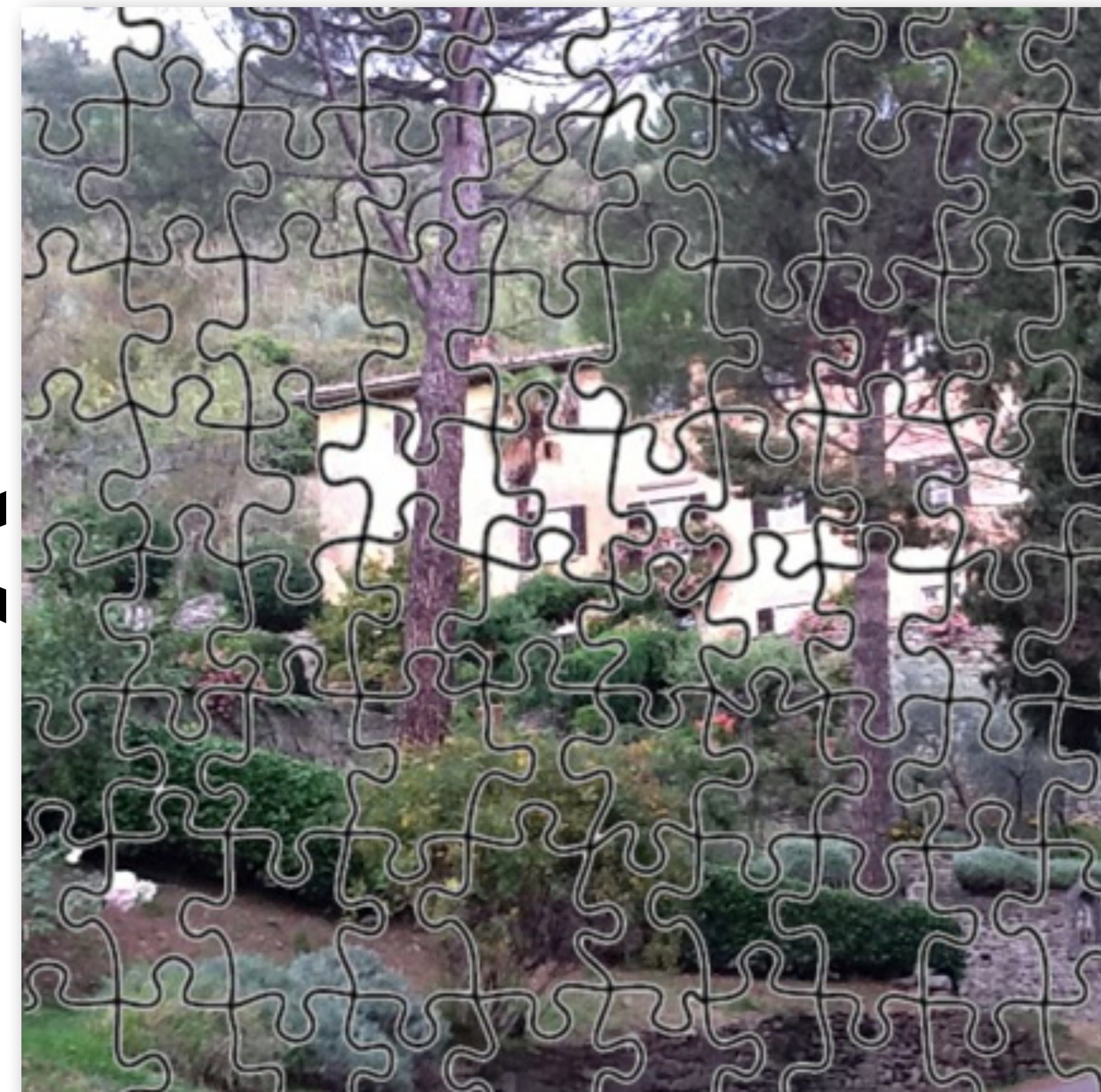


- The constraints exhibited in a given medium can channel dynamics to reduce the total work required to achieve a pre-determined functional end state.

The emergence of interpretive dynamics

1. Homeodynamics (thermodynamics)

Spontaneous constraint dissipation, reduction of correlation, loss of symmetries, equilibration

e

2. Morphodynamics ("self-organization")

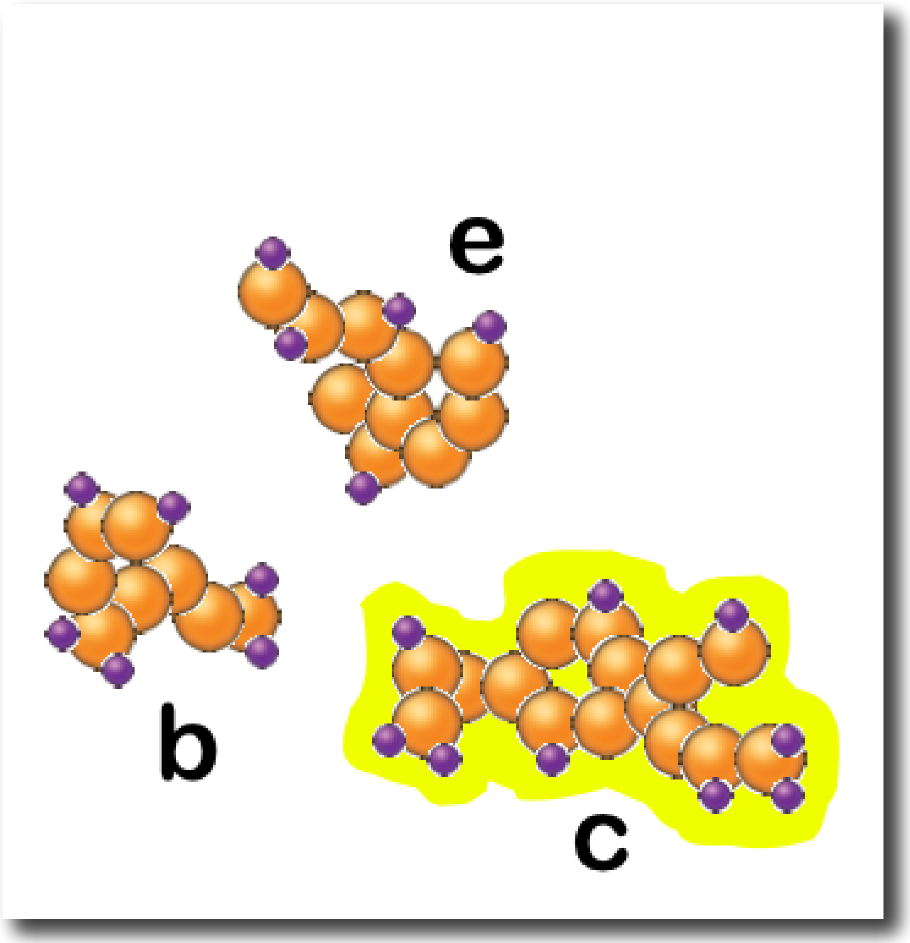
Amplification of system-internal constraints/regularities due to the persistent extrinsic reversal of spontaneous dissipation

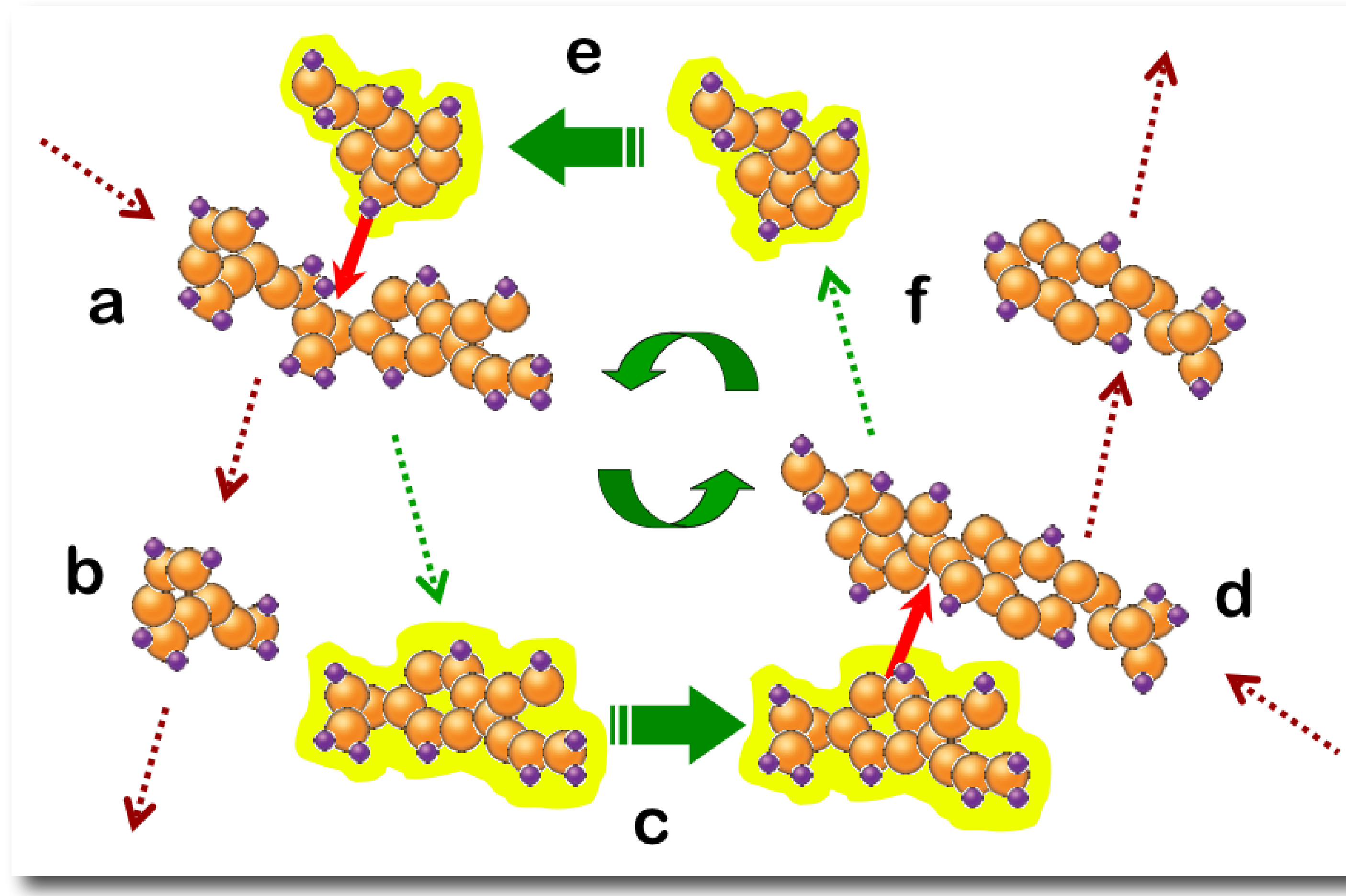
e

3. Teleodynamics (life and semiosis)

Self-reproducing/maintaining constraints producing synergistic interdependent coupling of morphodynamics

Reciprocal catalysis (autocatalytic set)

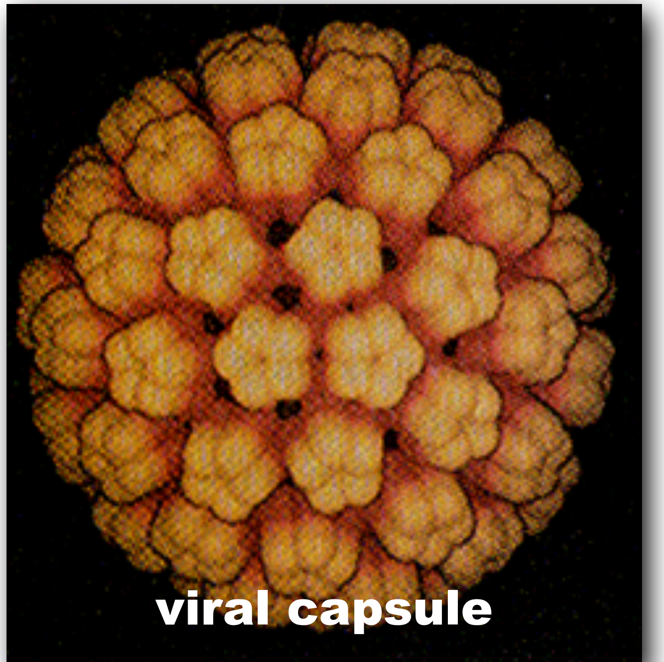


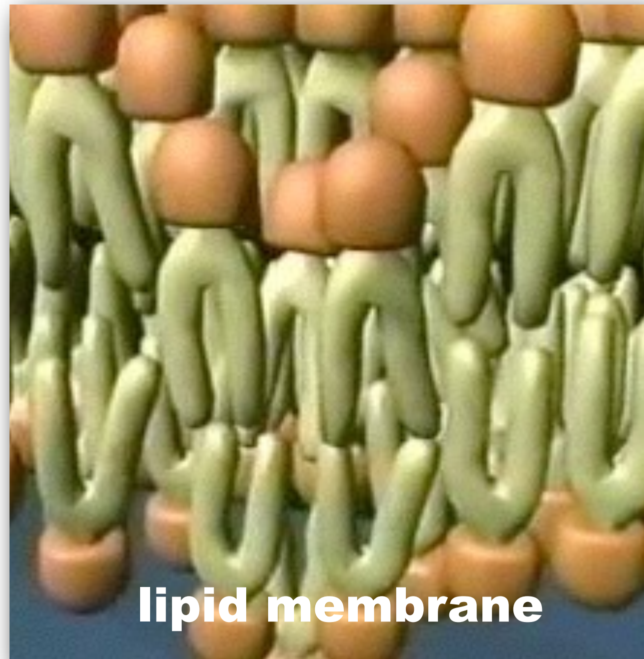


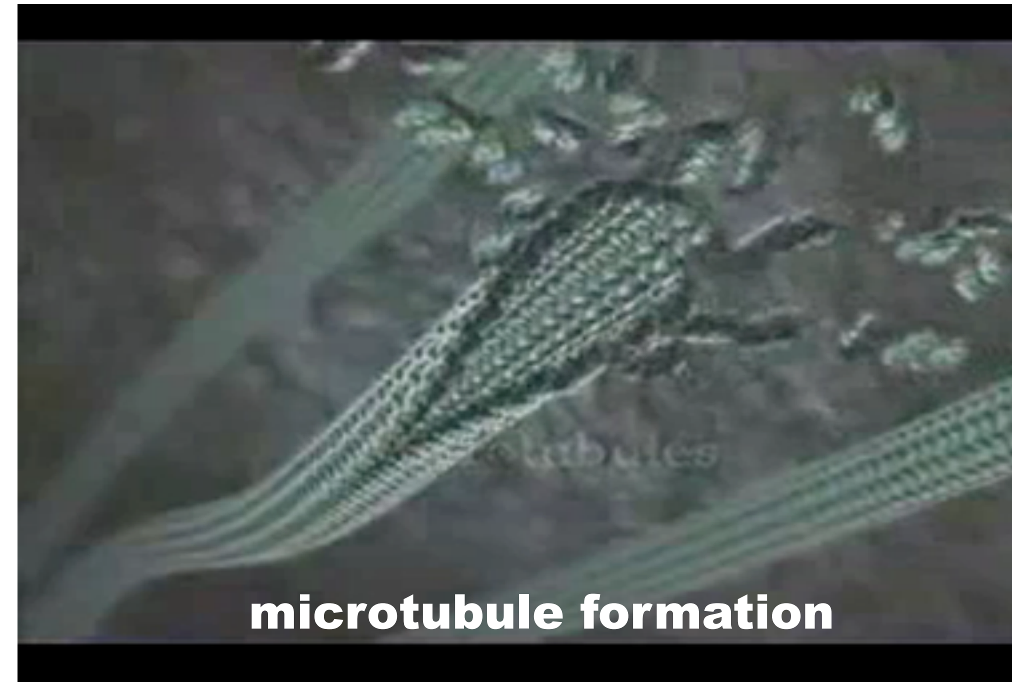
Lysis of molecule **a** into molecules **b** and **c** by catalyst **e** releases the energy of the broken covalent bonds

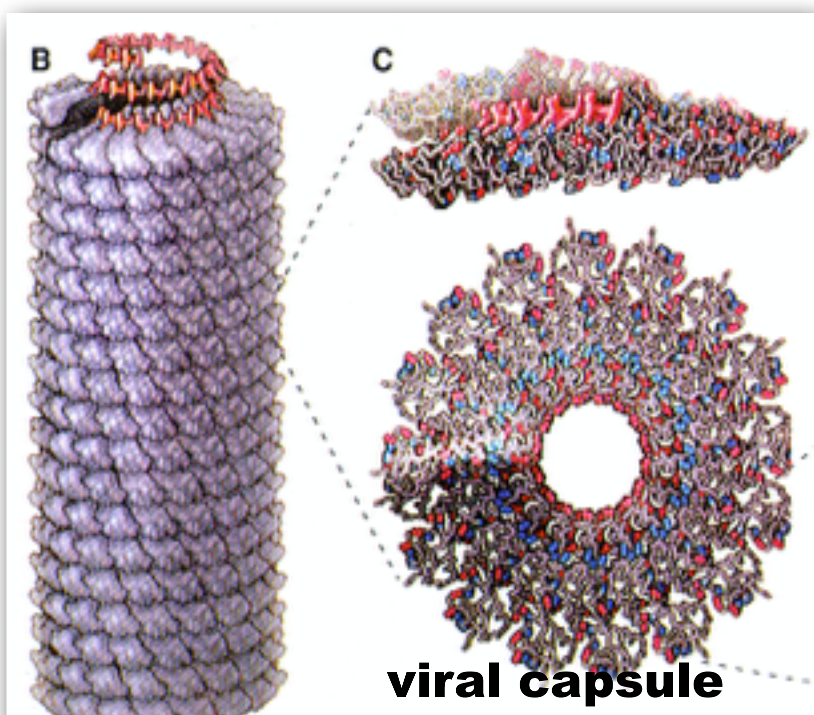
Reciprocal catalysis occurs when one catalytic reaction produces a product that catalyzes a second reaction which produces a product that catalyzes the first (and may involve multiple steps)

The morphodynamics of self-assembly









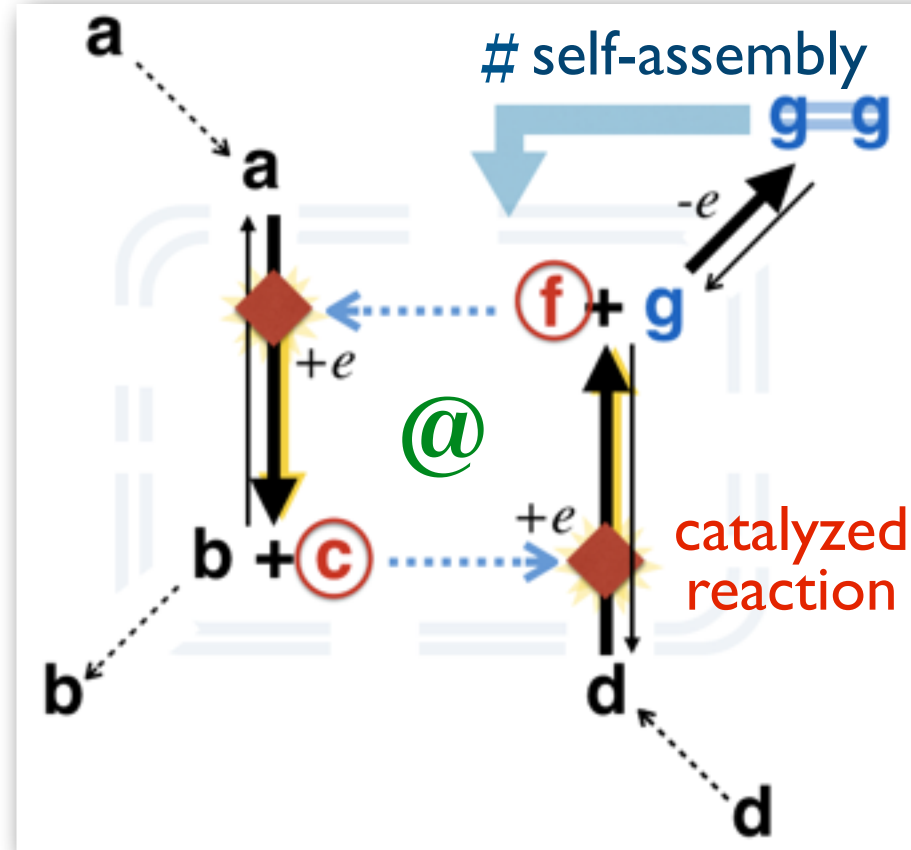
Self-assembly occurs when the complementary geometry of molecular surfaces facilitates spontaneous tesselation into sheets, polyhedrons, tubes, etc.

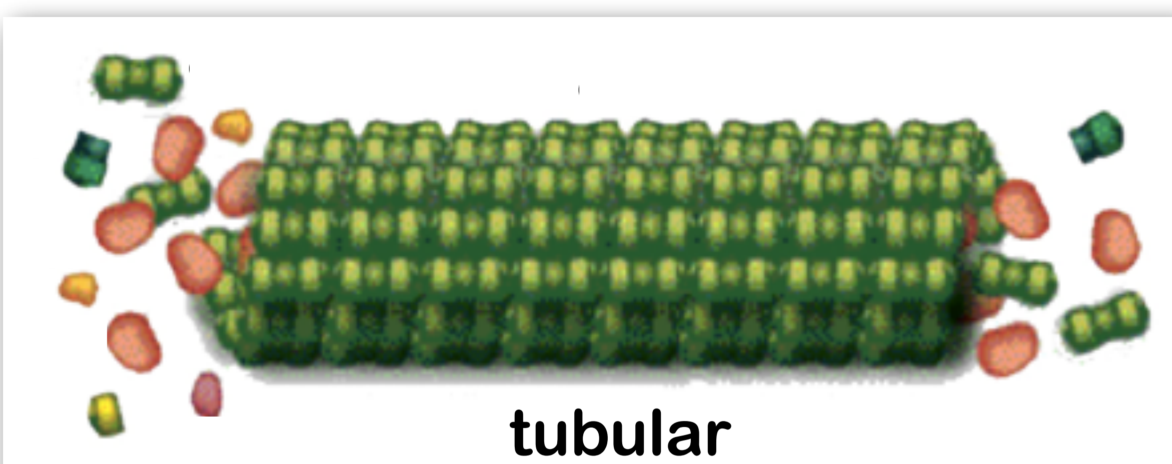
Morphodynamic processes that each produce the others' boundary constraints

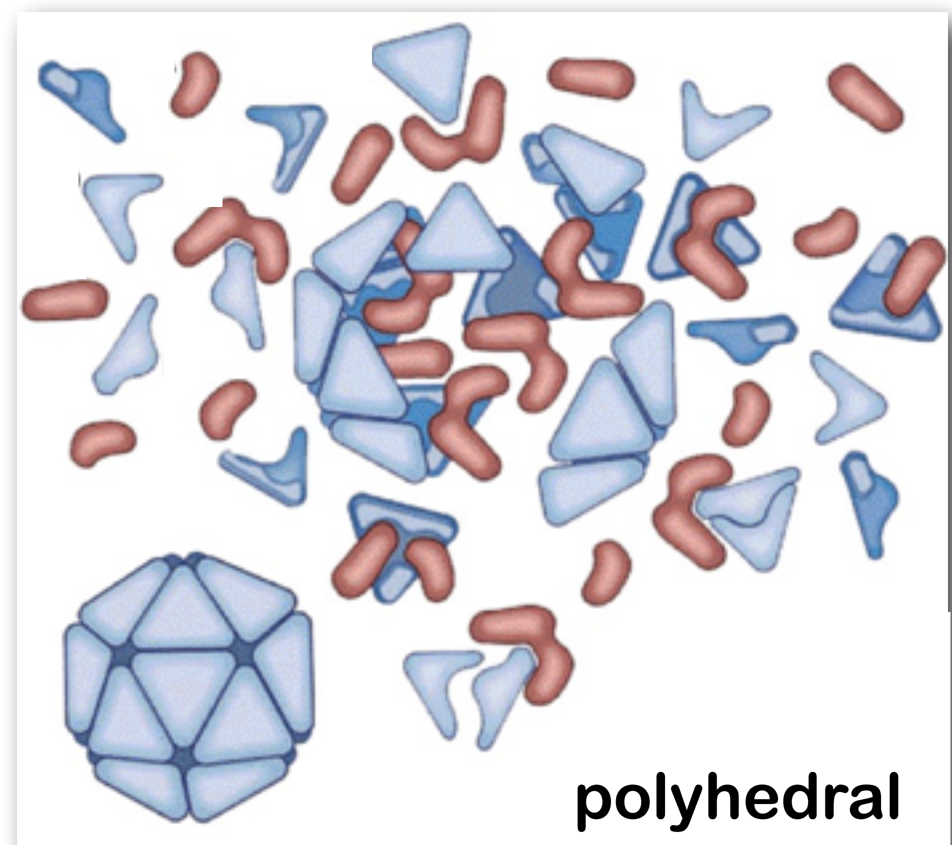
1. ***Reciprocal catalysis*** plus biproduct
   - Spontaneously self-amplifying catalytic chain-reaction with at least one energy-liberating reaction
   - Σ ***Produces*** high locally asymmetric concentrations of a small number of molecular species
   - Δ ***Requires*** limited diffusion of interdependent catalysts
2. Enclosure by ***self-assembly***
   - Spontaneous molecular tesselation into a closed structure due to stereochemical matching
   - Δ ***Produces*** constraint on molecular diffusion
   - Σ ***Requires*** persistently high local concentrations of a single species of component molecule

Autogenesis: simplest interpretive system

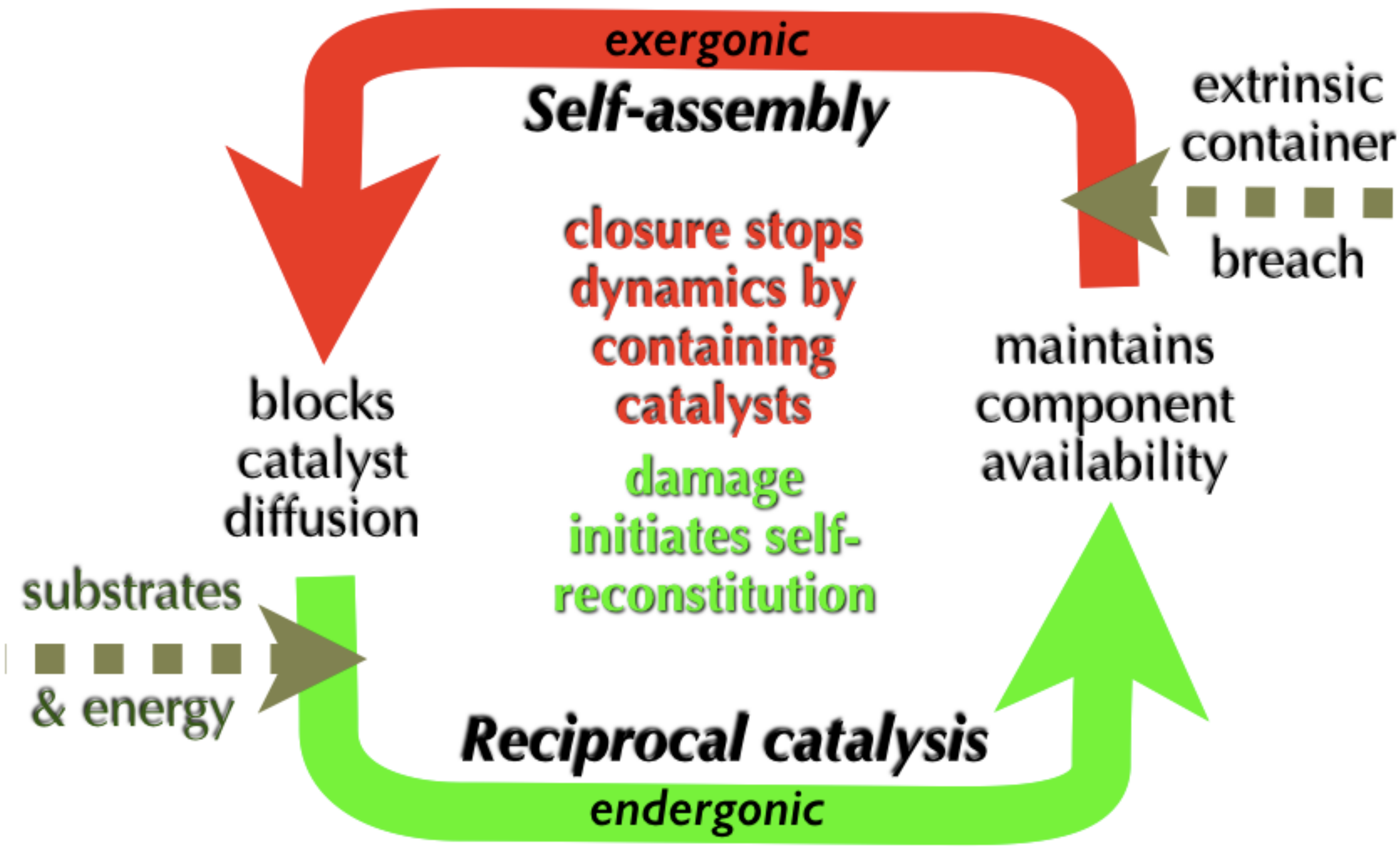
When one of the molecular products of a reciprocal catalytic cycle[@] tends to self-assemble[#] into a closed structure, encapsulation of the ensemble of reciprocal catalysts becomes likely.



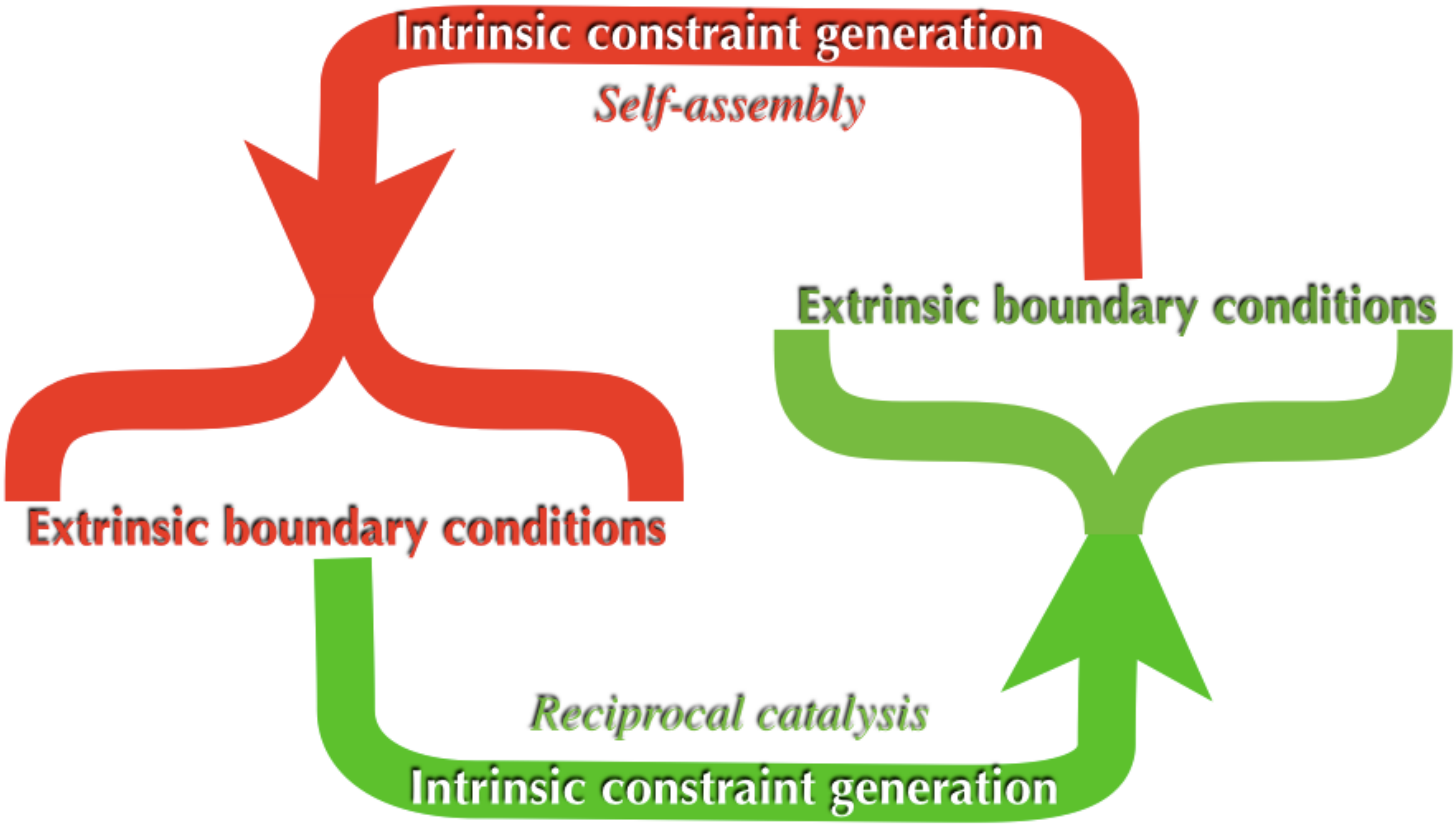




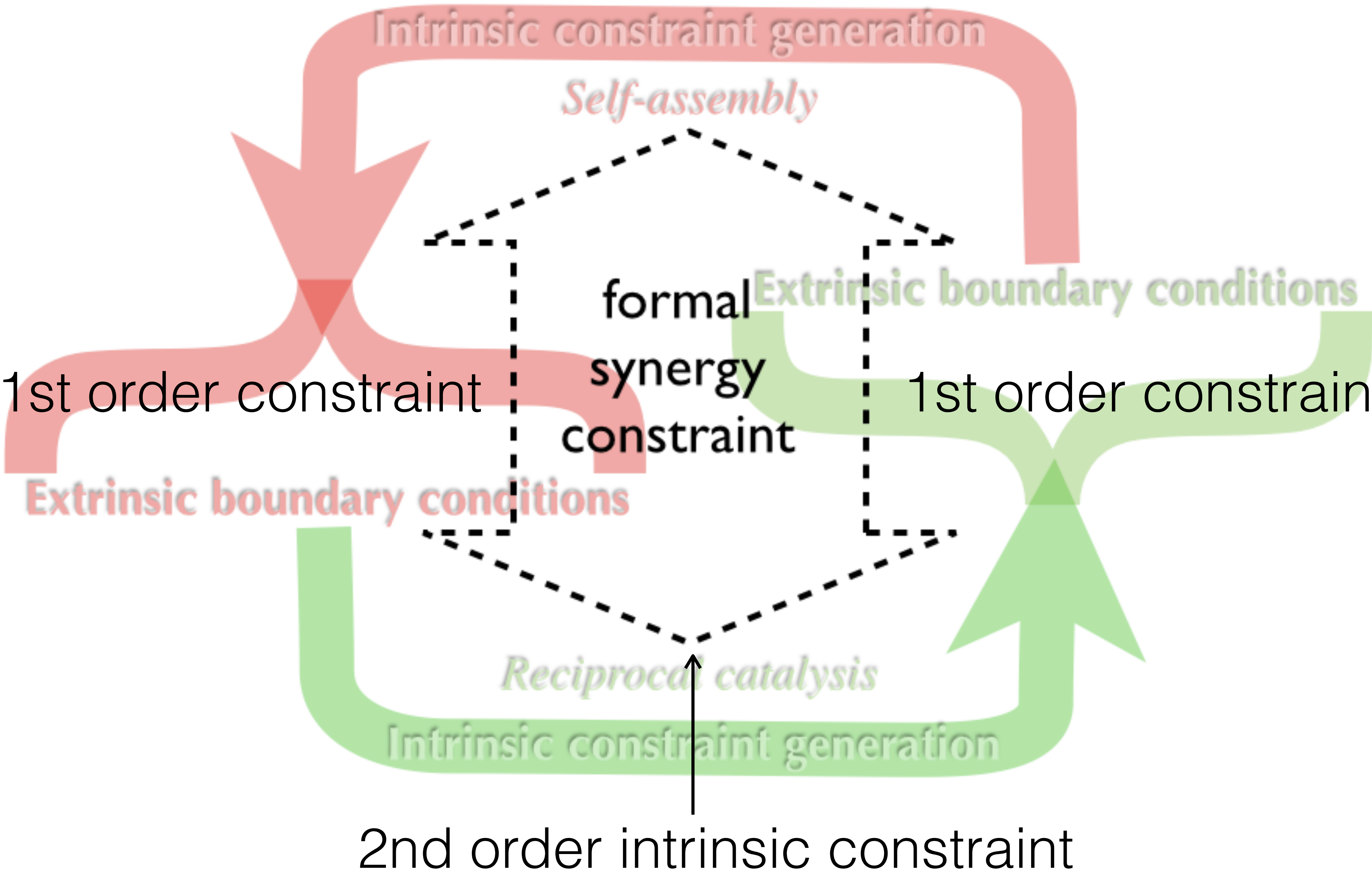
Morphodynamic constraint-reciprocity => autogenic work cycle



Internal reciprocally-generated boundary conditions enable preservation of the far-from-equilibrium dissipative system



This reciprocity constitutes a higher-order formal constraint that can be preserved indefinitely despite change of substrates



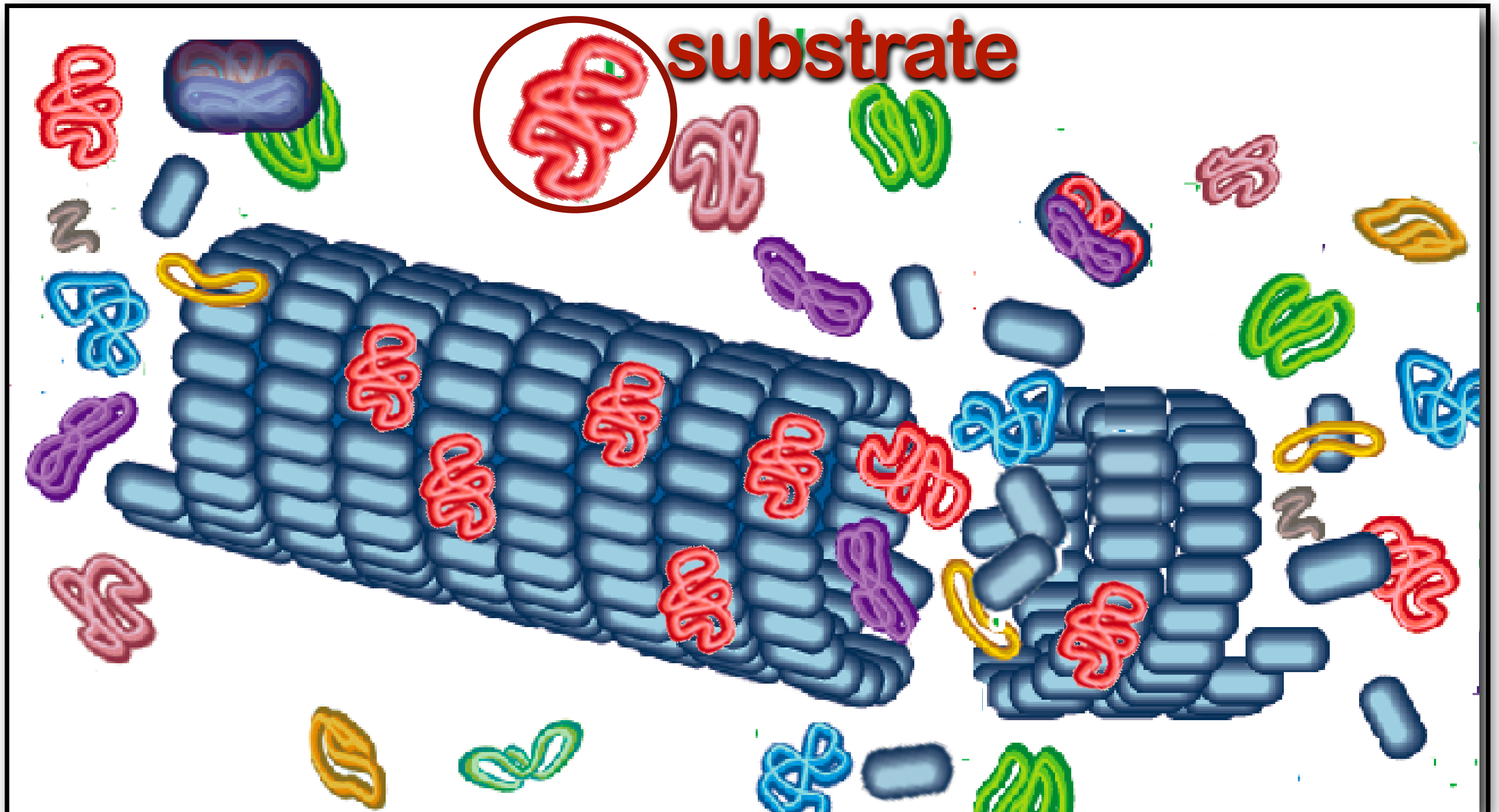
The multiple realizability of self

- The ***higher-order synergy-constraint*** that constitutes autogenesis ***persists irrespective of changes*** of the underlying substrates and irrespective of whether the system is in dynamic change or inert.
- It is therefore not vested in any particular component substrate or physico-chemical process.
- It is ***substrate-transferrable; multiply realizable***; and ***formal*** even though physically embodied
- It constitutes the ***continuity*** of an individual unit over time, and the ***information*** that gets ***reproduced and transmitted*** down a lineage.

Teleodynamics creates "self"

- It constitutes an ***individuated*** (i.e. closed and integrated) ***unit system*** because it is organized to actively initiate work to preserve its system-preserving-dynamical organization.
- This self-preserving/reproducing disposition creates an unambiguous ***self/non-self distinction*** with respect to potential dissipative influences and thereby creates an ***Umwelt***.
- This higher-order formal constraint on the synergy of component processes is a ***locus of agency*** that is intrinsic to the system yet not one of its components

Adaptive autogenesis = information



An autogen with a capsule surface structure that binds a substrate molecule and thereby increases shell instability in proportion to the number of bound substrates will increase the probability of selective dissociation in supportive conditions, and not otherwise.

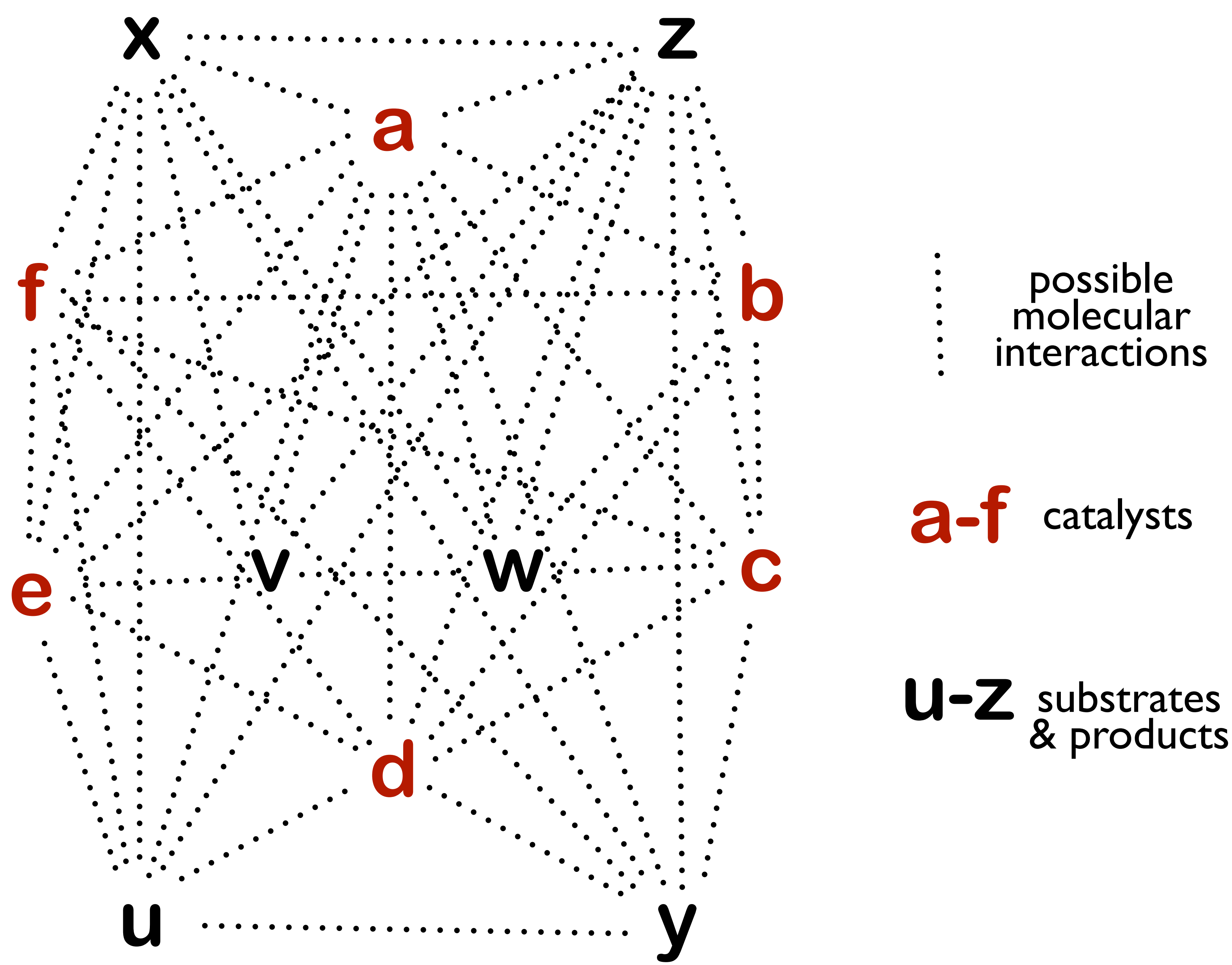
= *Information about* the relevant state of the environment with respect to its intrinsic tendency for self-preservation; its *telos*.

Limits to autogenic complexity

- A combinatorial catastrophe: A fundamental problem for systems employing many interdependent molecular interactions is the proliferation of competing side reactions.
- As the number of molecular species that need to interact increases (e.g. in reciprocal catalysis or self-assembly), the number of possible cross-reactions increases geometrically.
- Only a small fraction of these will be supportive of autogenesis and the proliferation of alternative interaction possibilities will compete with supportive interactions — using up critical components and wasting free energy.
- The increase in possible side reactions will slow the reconstitution and decrease the probability of persistence.
- So simple autogenic systems have limited evolvability.

The possible molecular interactions grow exponentially with increasing numbers

The increase in molecular components creates a combinatorial catastrophe making successful autogenesis improbable



Viable autogenic systems involve only a small fraction of the possible reactions

$$z \xrightarrow{a} b + e$$

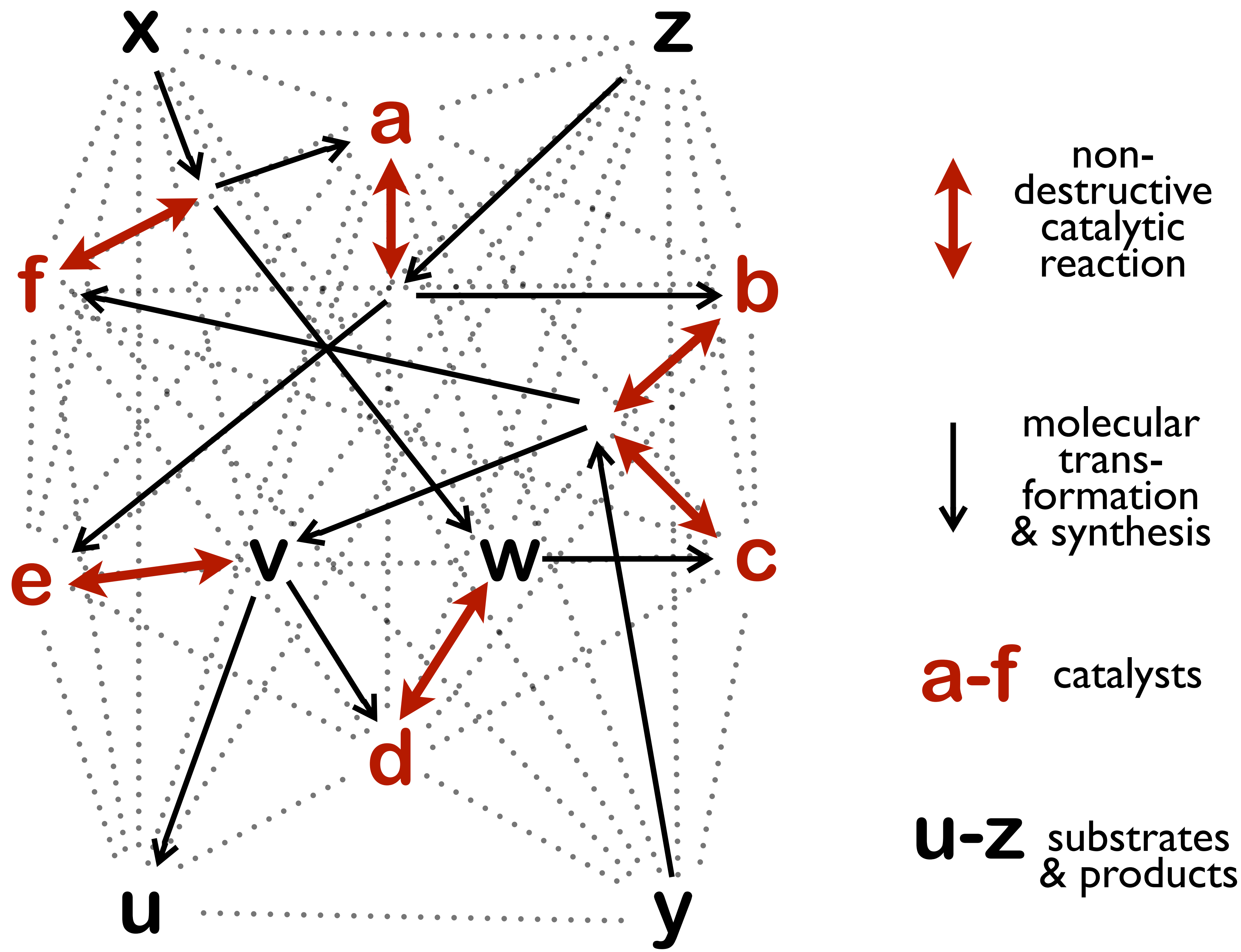
$$y \xrightarrow{bc} v + f$$

$$w \xrightarrow{d} c$$

$$v \xrightarrow{e} u + d$$

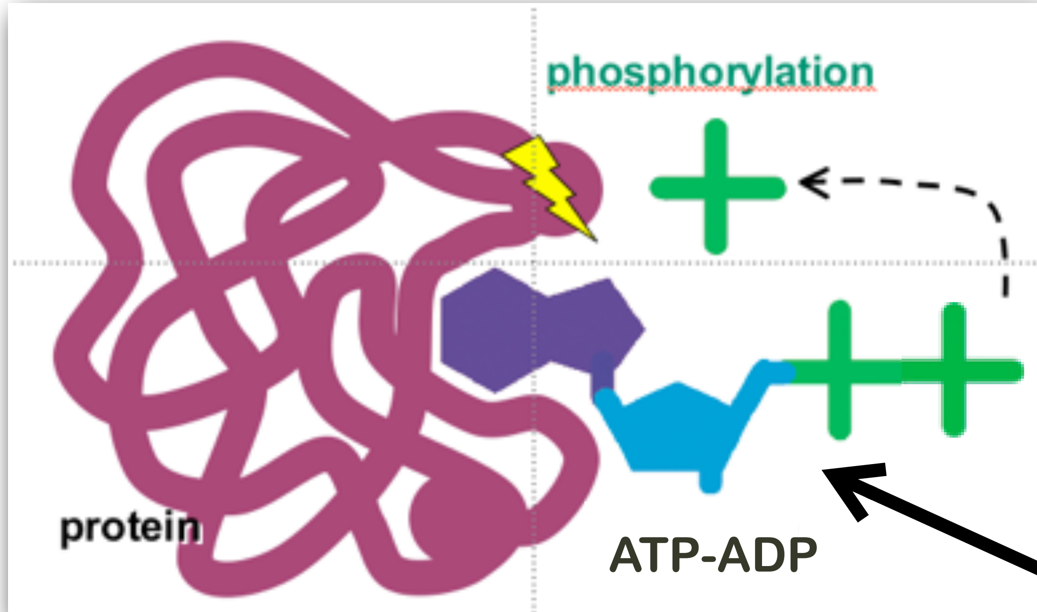
$$x \xrightarrow{f} w + a$$

Autogenic reactions

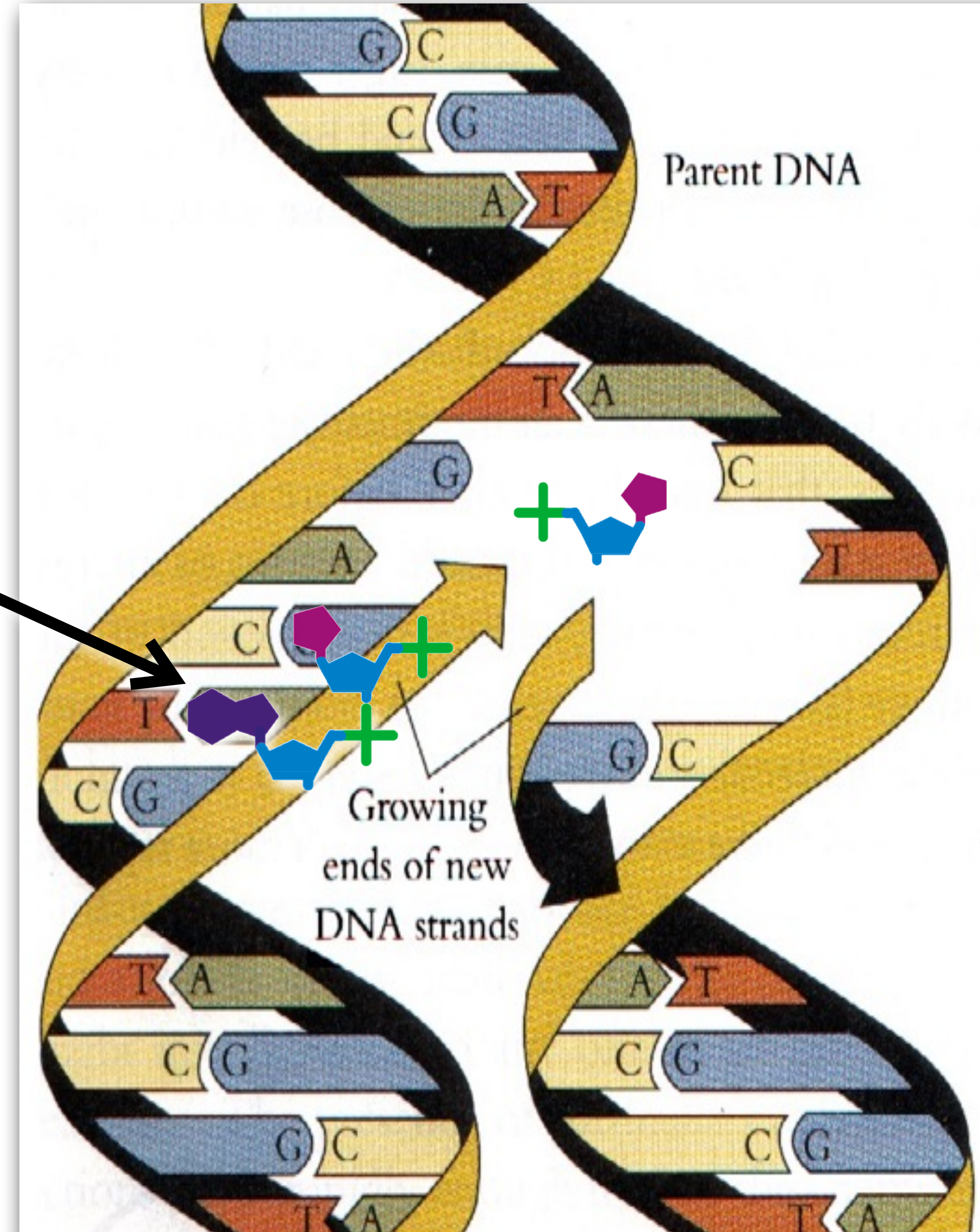


How can deleterious side reactions be selectively inhibited?

An energy / information coincidence?

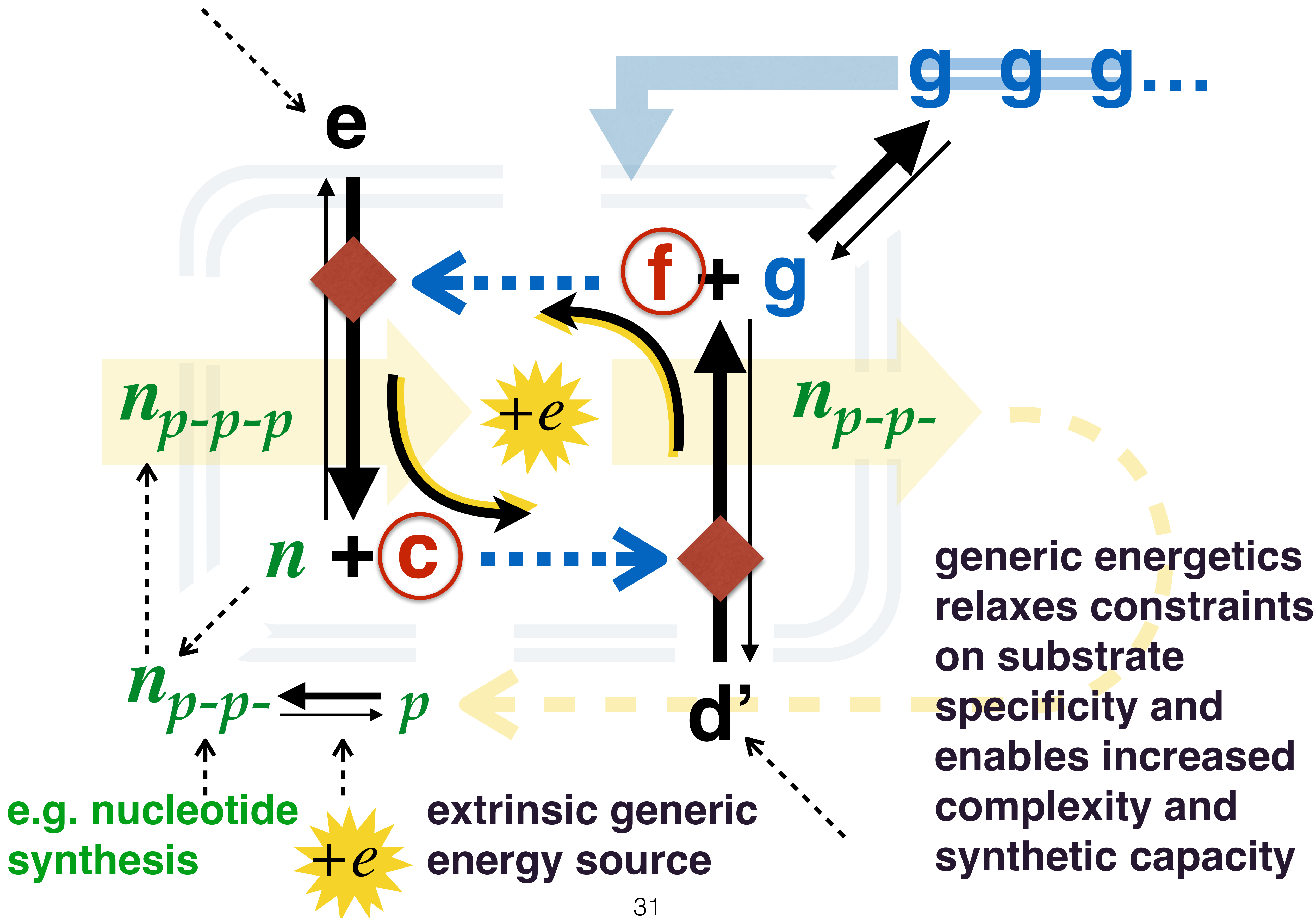


Phosphate (+) serves as the major vehicle for energy transfer and signaling in living cells. Phosphates can polymerize (++) and are conveyed throughout cells by three-part molecules (base-sugar-phosphate) such as ATP.



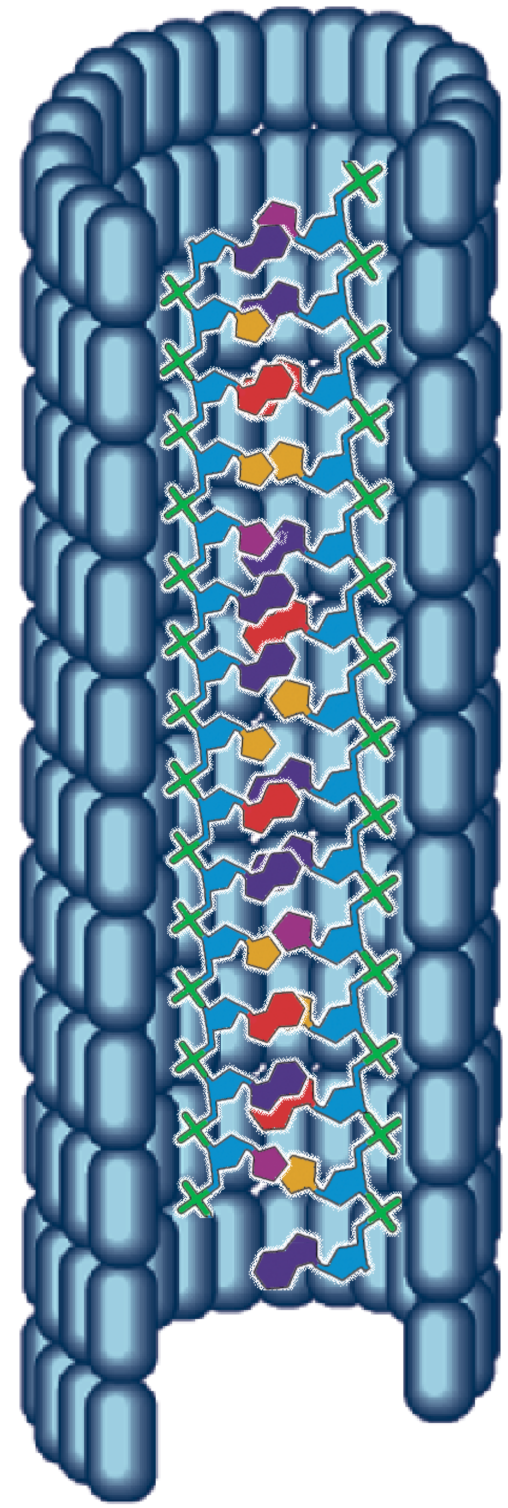
Why are they the building blocks of RNA and DNA?

Energy-capturing autogenic reaction network

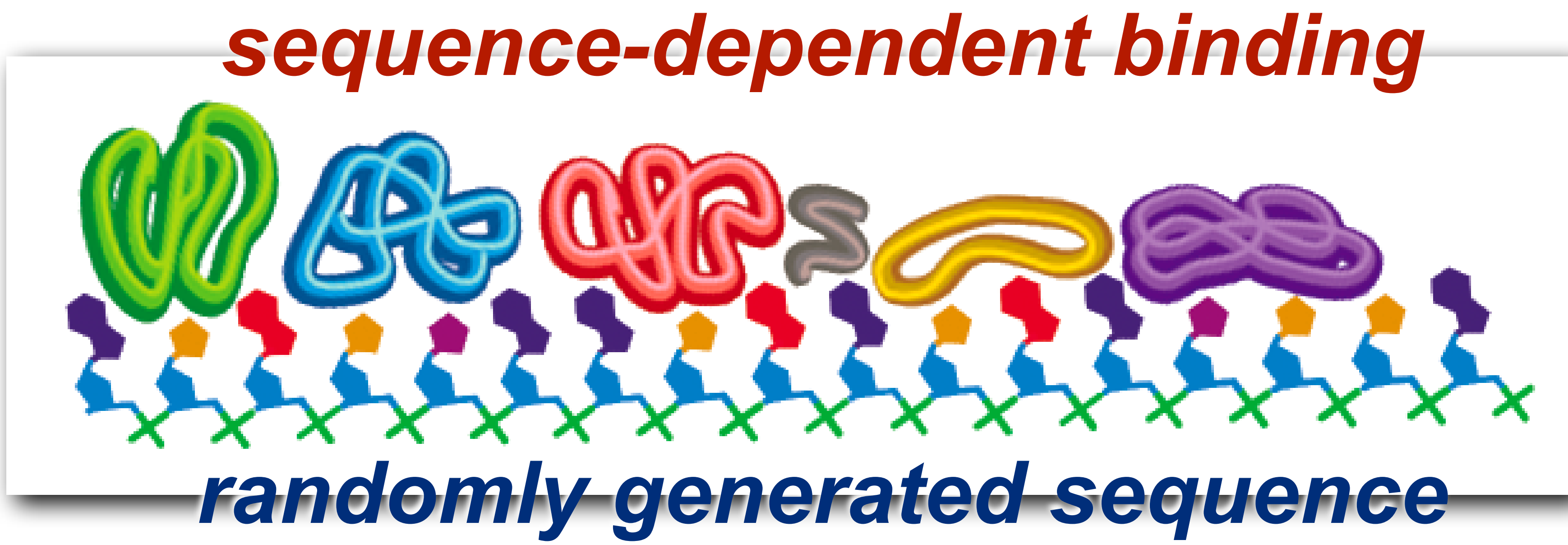


Nucleotide storage and phosphate protection by polymerization

- In their inert enclosed state autogenic systems do not require and may be degraded by free energy.
- Nucleotides can be sequestered and phosphate residues made stable by nucleotide polymerization.
- This allows storage for later use via depolymerization.

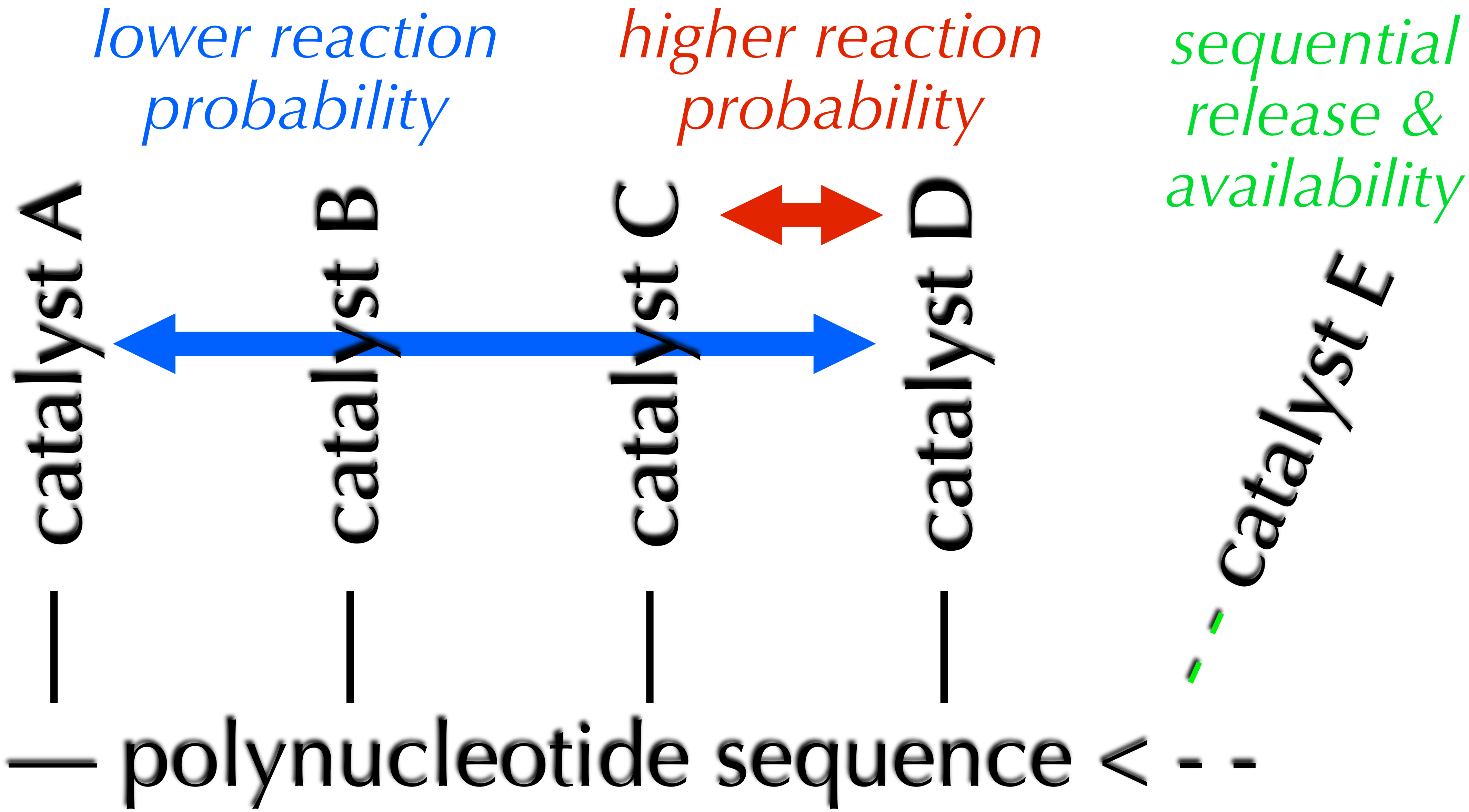


Sequence-specific protein binding to a polynucleotide string



- To the extent that different nucleotides are not distinguished with respect to their phosphate binding capacity, the polymerization of nucleotides will be unbiased with respect to order in the inert phase of autogenesis,
- but different sequences will tend to have different affinities for binding specific proteins.

Alignment of catalysts on a polynucleotide chain can bias catalytic reaction probabilities

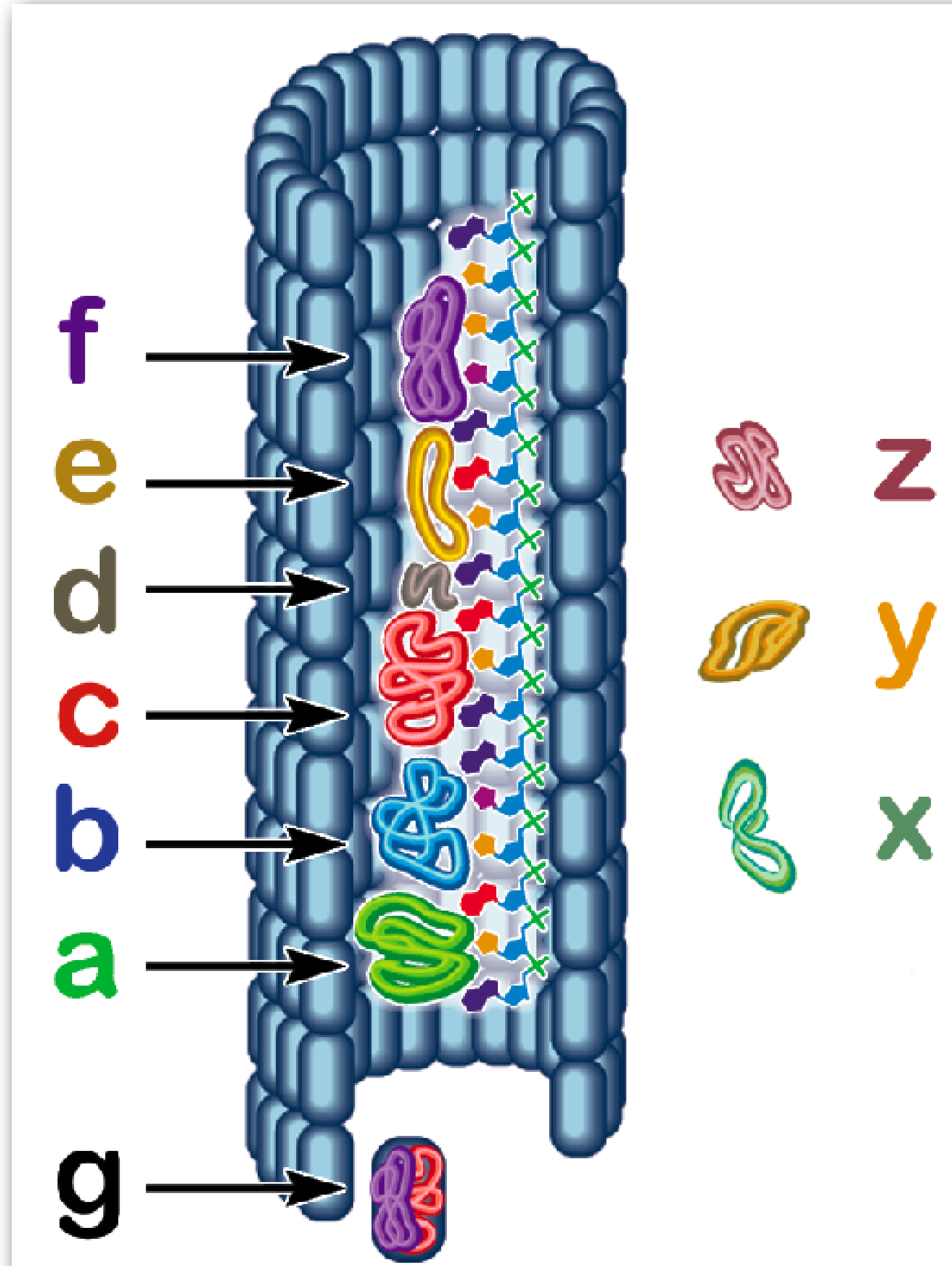


Template binding order -> reaction network constraint

- Template structure can constrain reaction probabilities to minimize unuseful interactions

1. a+z = b+e
2. **a+b**+x = c+b+e
3. **b+c**+y = f+a+d
4. **c+d+e+f** = g+d+e

template-biased reactions



… leads to sequence-specific selection

- The relative proximity and orientation of catalyst molecules on a polymer template will bias the reaction probabilities between them due to distance and sequential timing of release.
- Sequences that constrain catalyst interaction probabilities closer to the optimal interaction network will be preferentially retained because of higher reproduction and repair rates.
- The template molecule thereby offloads some fraction of the higher order dynamical synergy constraint onto a structure that is effectively external to autogenic dynamics but constraints it.
- *A preliminary to the origin of genetic information?*