Lessons from the bottom up construction of minimal life

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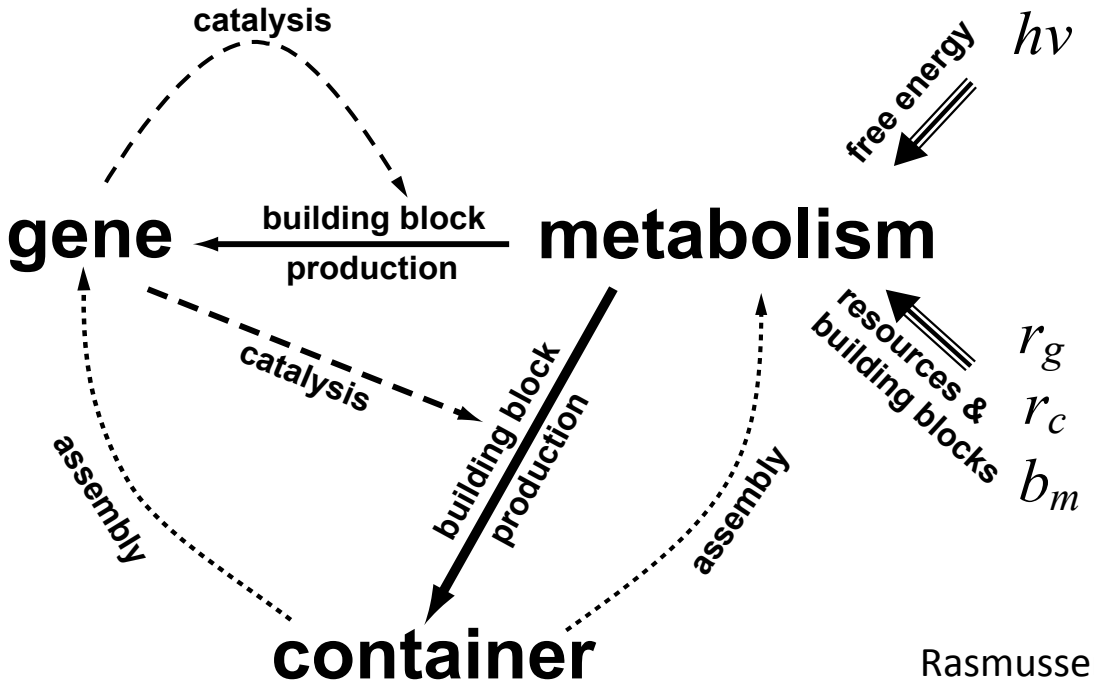
Conjecture: Larger systems, more dimensions, higher object complexity (diversity) enables higher order functionalities (through richer interactions / more information channels), which in turn is *necessary* for open-ended evolution.

However, added component complexity/diversity is *not* a *sufficient condition* for richer sets of functionalities.

We study how the environment together with a local self-assembly **(dG < 0)** and self-organization **(dG >0)** may play together to generate (minimal) self-replicating physicochemical systems.



Rasmussen et al., *Artificial Life* 2003

Protocells of this (together with other bottom up**) design**(s) **apparently lacks an ability to evolve in an open-ended manner. Only optimization of its metabolic rate seems possible** through a selection of appropriate compositional information on its "genes".

Question: Is a richer environment enough to expand a protoecell's evolutionary potential for novelty? Thus should we "just" expand the systems space?

Dynamical hierarchies as a design principle

Level of Description	*Molecular Structure & Order*	*Observed (Emergent) Functionality*
Level 3	vesicle, redox complexes & templating polymers (5th order)	information storage evolution
	vesicle & redox complexes (4th order)	auto-catalytic self-reproduction
	micelles or vesicles (polymers & water) (3rd order)	inside/outside permeability
Level 2	Polymer or redox complex & water (2nd order)	elasticity, radius of gyration, electron transfer
Level 1	water & monomers (1st order)	phase separation pair distributions

Figure 7. Dynamical hierarchy for a proto-organism. Note that this system has three natural levels of description. Nevertheless, it is a fifth-order structure because it is defined by functionalities that are observable only after two additional assembly processes defined after third-order lipid aggregates have occurred.

Rasmussen et al., *Artificial Life* 2001

Object complexity/diversity increase <-> Generated higher order functions

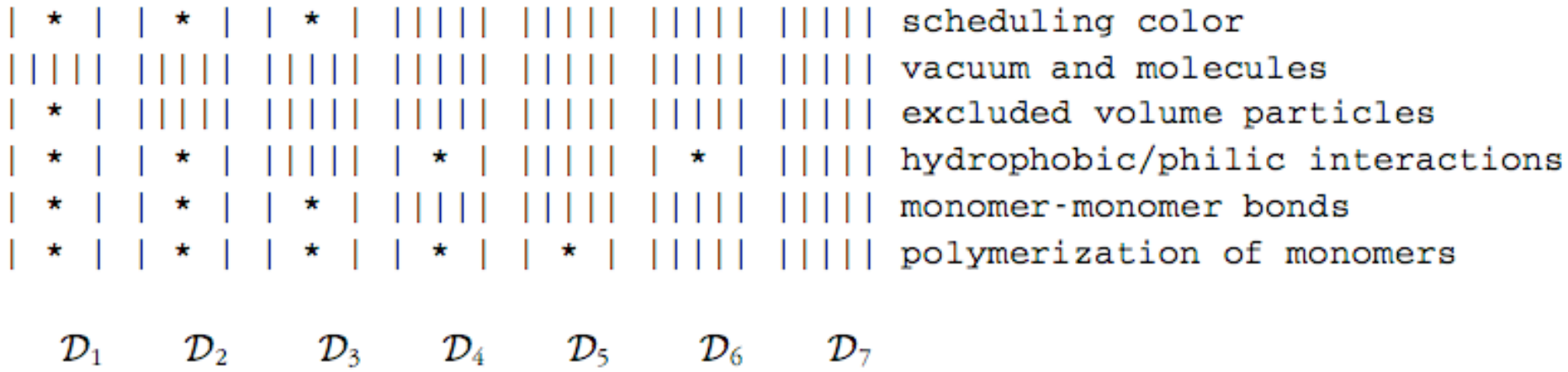


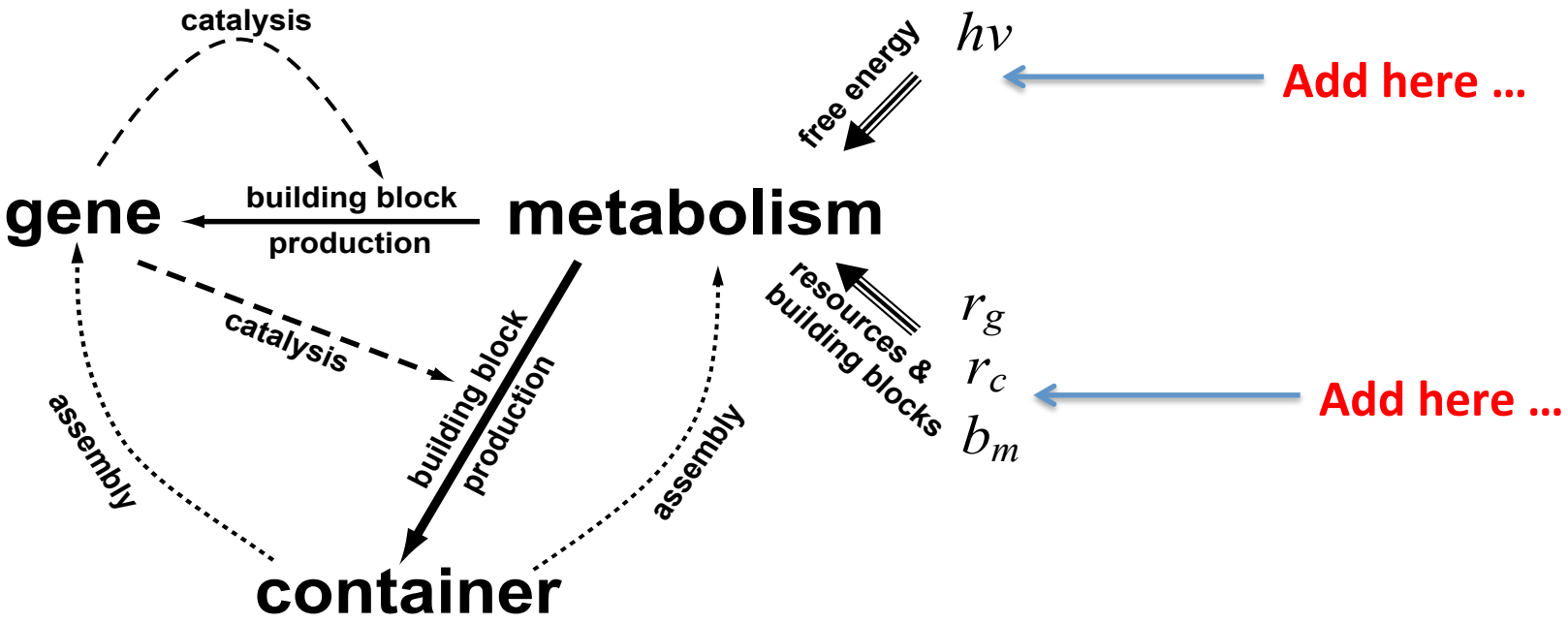
Figure 5. Definition of object complexity as the number of active variables in the data structure. $\mathcal{D}_v$ labels classes of systems wherein the variables indicated by lines are activated and the variables marked by asterisks are empty. $\mathcal{D}_1$ produces fluid dynamics as defined through the traditional lattice gas automata. $\mathcal{D}_2$ produces monomer dynamics with excluded molecular volumes. $\mathcal{D}_3$ produces aggregates of hydrophobic monomers surrounded by water. $\mathcal{D}_4$ produces polymer dynamics. $\mathcal{D}_5$ produces micelles, vesicles, and membranes starting from polymer interactions. $\mathcal{D}_6$ produces polymers from monomers through a polymerization process that can assemble. $\mathcal{D}_7$ produces micelles, vesicles, and membranes from polymers that are polymerized from the initial monomers.

Rasmussen et al., *Artificial Life* 2001

A combinatorial explosion in interactions result from adding new objects. However, the object complexity addition should be done "with care".

More energy transduction components -> different metabolic processes -> different building blocks …

More lipid/information building blocks -> e.g. different containers / information molecules -> different higher order properties …



But the system easily turns into black tar … so add with care

Conjecture: Larger systems, more dimensions, more object complexity (diversity) enables higher order functionalities (through richer object interactions), which in turn is *necessary* for open-ended evolution.

However, added component complexity/diversity is *not* a *sufficient condition* for richer sets of functionalities and the kind and order in which to add components is not arbitrary…

Could a "good" component inclusion ability be a property developed by the living system or be a property of the fitness landscape? Or are we left with trail and error?