The Evolution of Identity and Modularity in Nature and Computation

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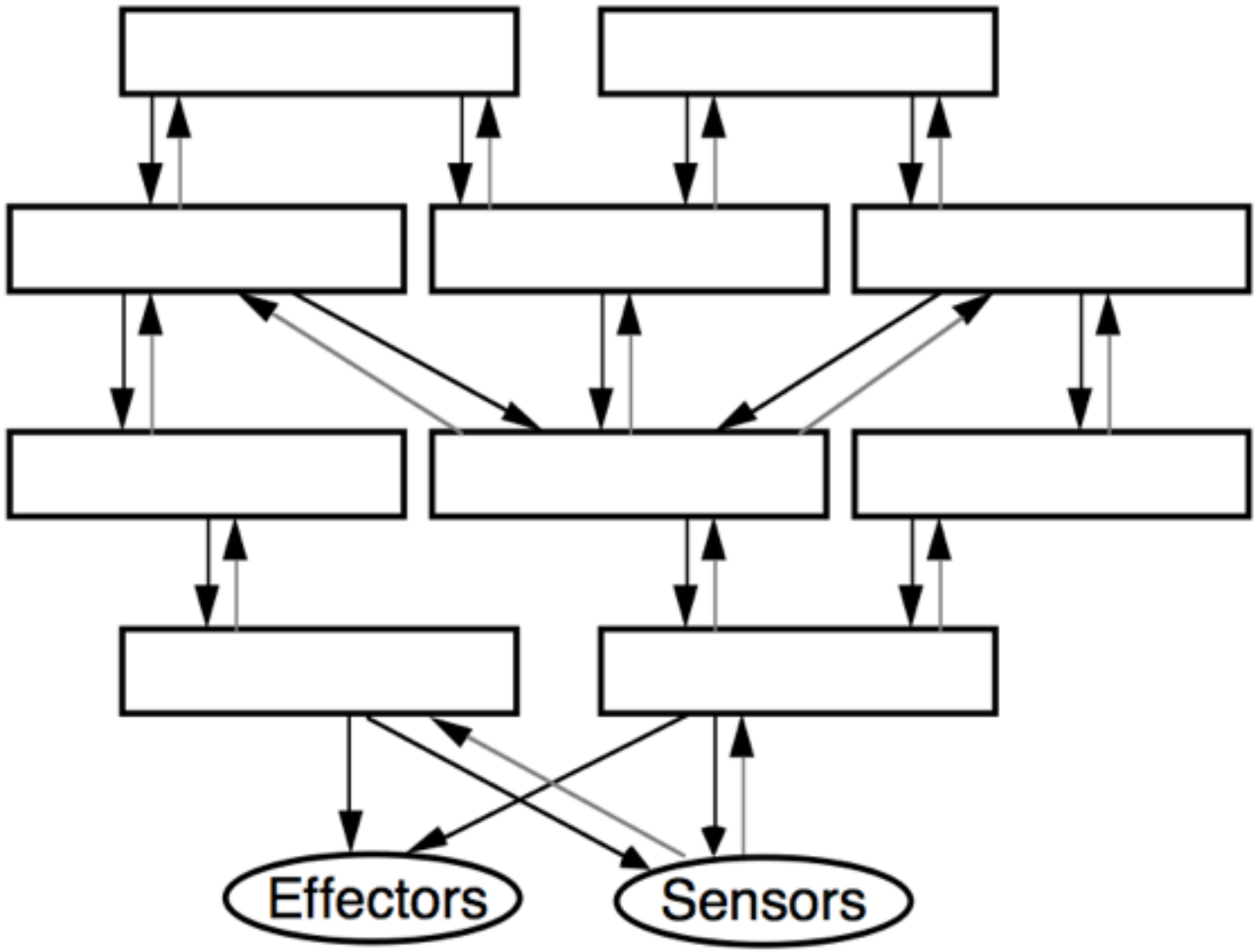
Overview

- Modularity
- Identity
- Evolving computer programs
- Evolving modular programs
- Implications

Modularity is Everywhere



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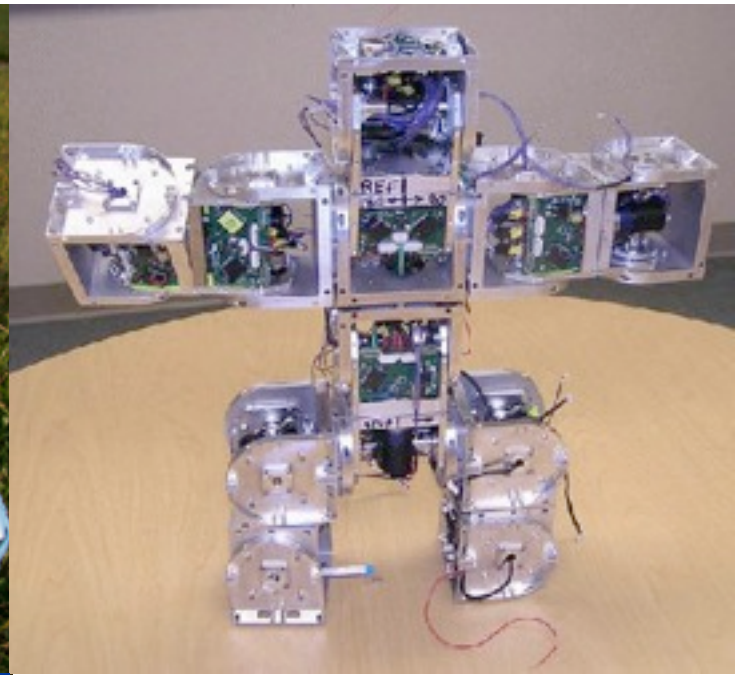
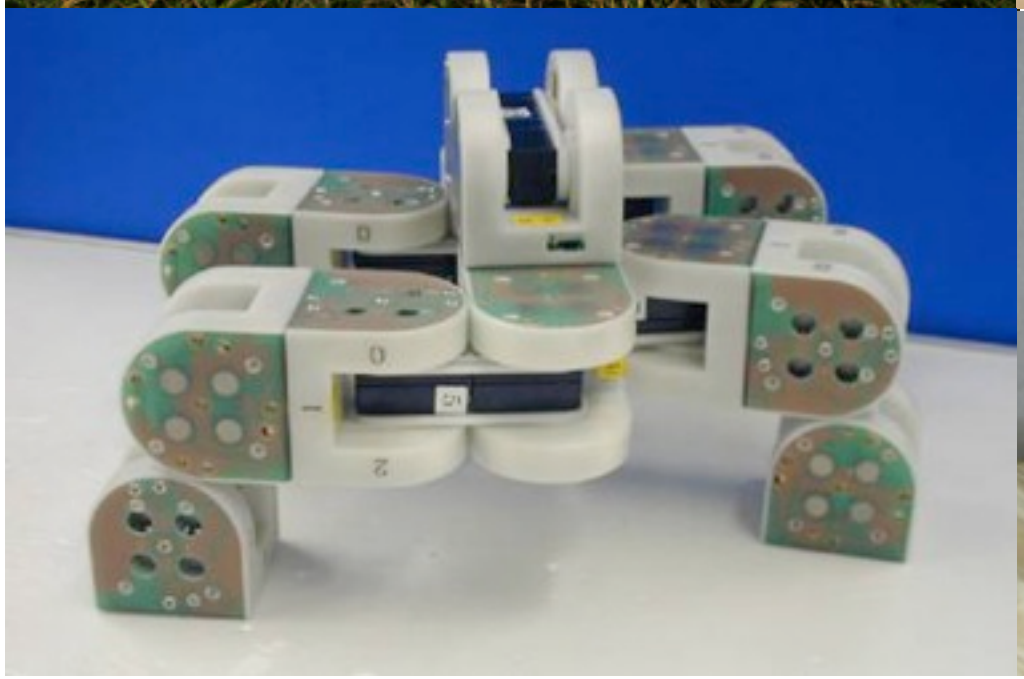
http://talkinterior.com/interior-design-vita-minimalist-modular-home/

http://www.e-potpourri.com/index.php/2008/02/02/octopus-studios-silverfish-aquarium-boasts-modern-modular-design/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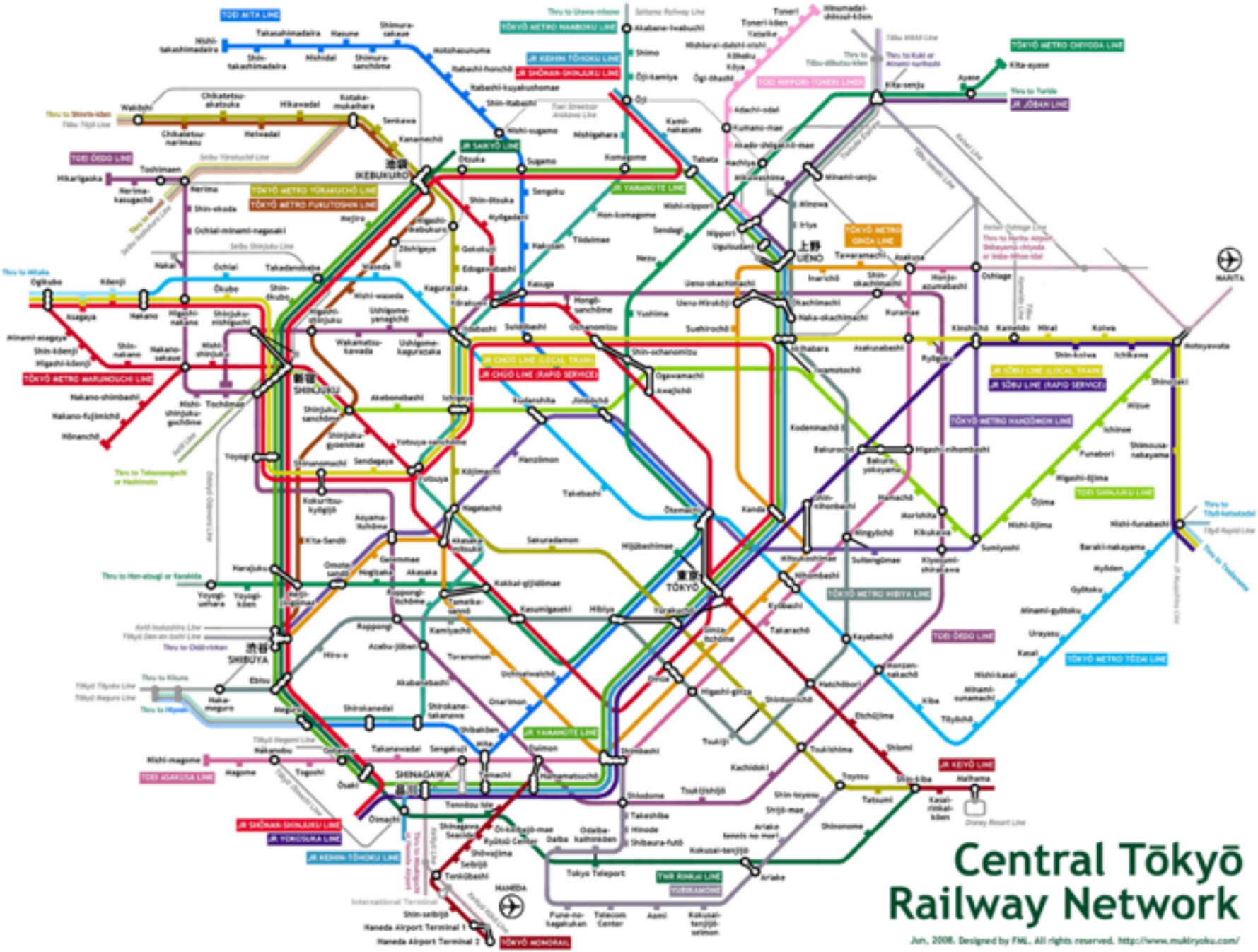


http://mappery.com/map-of/Tokyo-Metro-Map

Modularity in Software

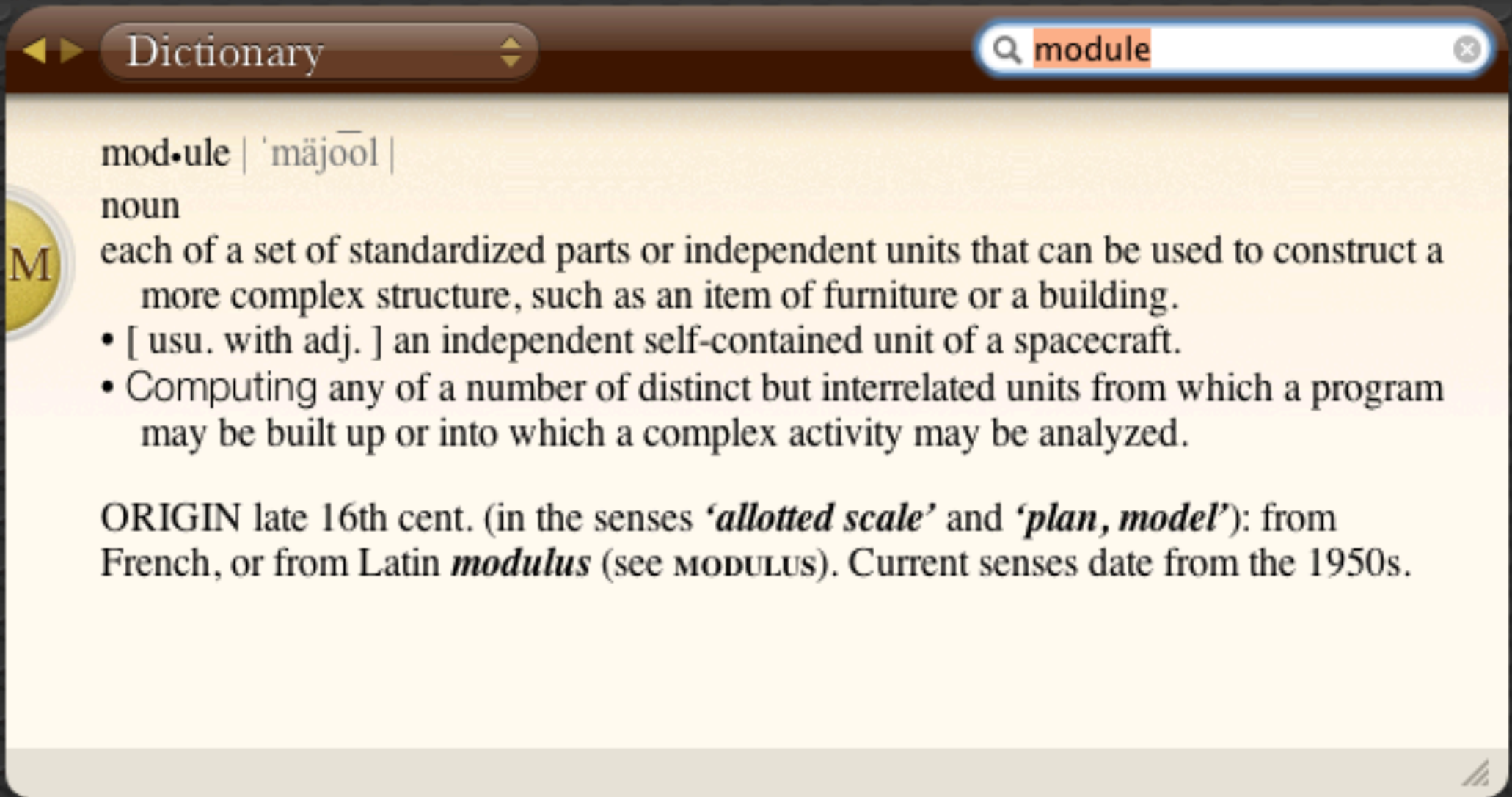
- Pervasive and widely acknowledged to be essential
- Modules may be functions, procedures, methods, classes, data structures, interfaces, etc.
- Modularity measures include coupling, cohesion, encapsulation, composability, etc.

http://en.wikipedia.org/wiki/File:Sa-fern.jpg

http://a-z-animals.com/animals/centipede/

Cognitive Science

- Long history of modularity theories: Gall, ... Simon, ... Fodor, ... Cermak and Craik, ... Gardner, ... Jackendoff, ... Grafman, ...
- Simon's "nearly decomposable systems"
- Fodor's features: domain specific, mandatory, fast, encapsulated, fixed architecture, characteristic patterns of ontogeny and failure
- Central vs. input systems
- Modest vs. massive


Dictionary
module
mod•ule | ˈmäjo͞ol |
noun
each of a set of standardized parts or independent units that can be used to construct a more complex structure, such as an item of furniture or a building.
• [usu. with adj.] an independent self-contained unit of a spacecraft.
• Computing any of a number of distinct but interrelated units from which a program may be built up or into which a complex activity may be analyzed.
ORIGIN late 16th cent. (in the senses 'allotted scale' and 'plan, model'): from French, or from Latin modulus (see MODULUS). Current senses date from the 1950s.

Questions

- **Why** are modules everywhere?
- What are they good for?
- Where do they come from?
- What conditions permit or facilitate their emergence?

Identity

- How are modules recognized by other components of a system?
- Where do module identities come from?
- How can module identity co-evolve with modular architecture?

Holland's Tags

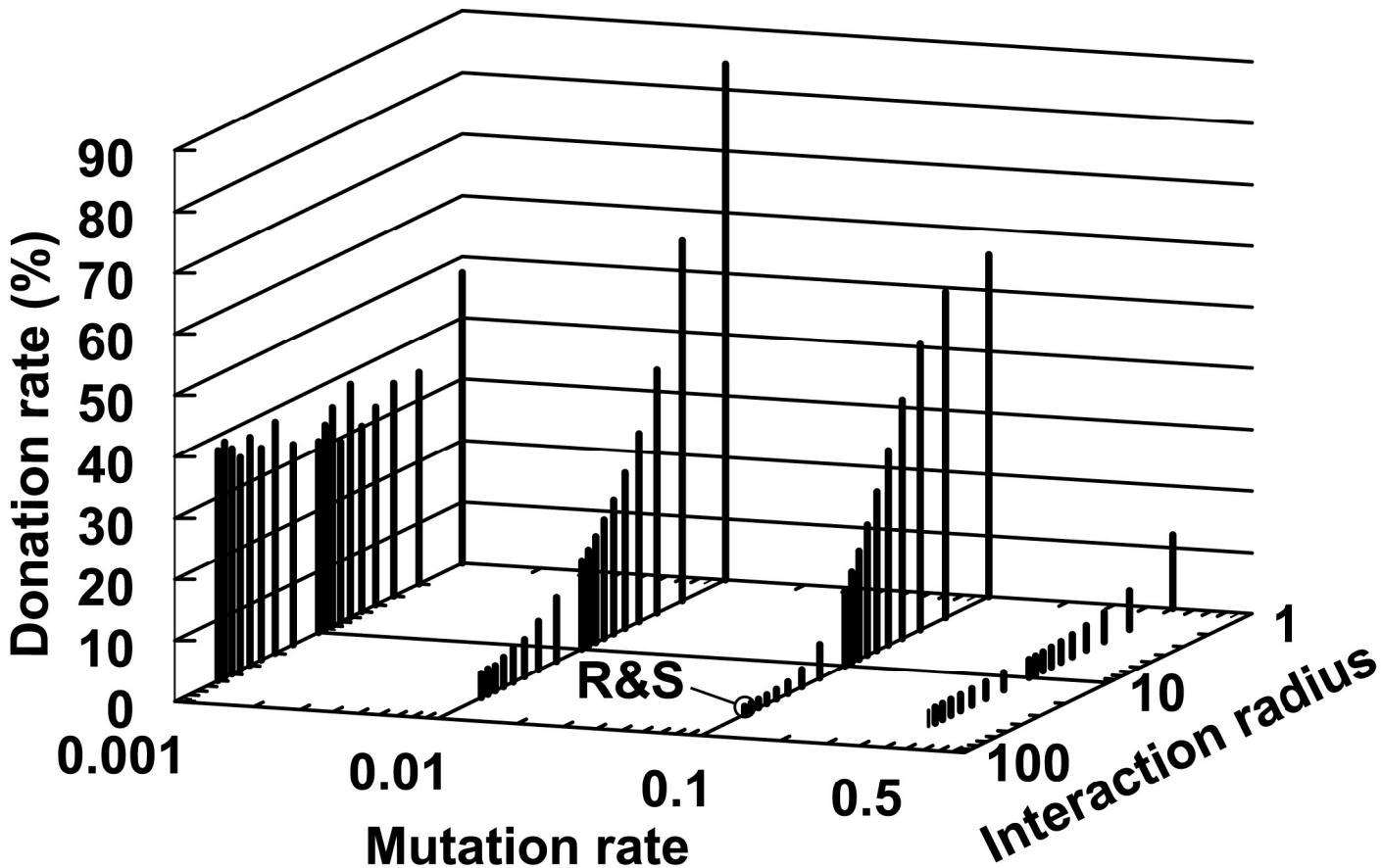
- Initially arbitrary identifiers that come to have meaning over time
- Appear to be present in some form in many different kinds of complex adaptive systems
- Examples range from immune systems to armies on a battlefield
- A general tool for the support of emergent complexity

Evolution of Altruism

- Puzzles/challenges/results since Darwin
- Explanations of altruism toward:
  - Kin
  - Reciprocating partners
  - Agents with good reputations

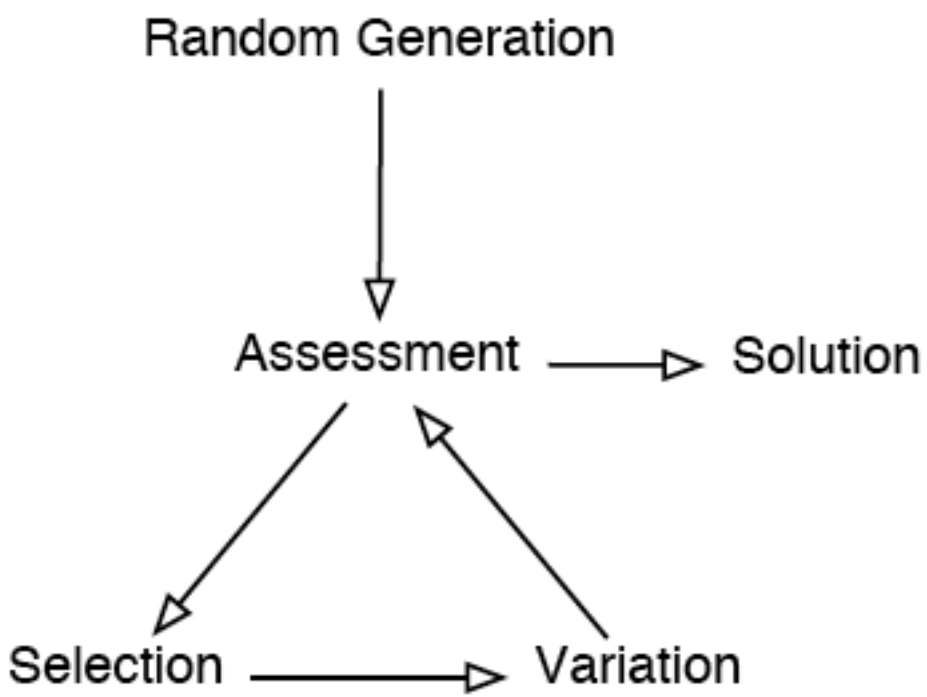
Tag-Based Altruism

- Individuals have tags and tag-difference tolerances
- Donate when Δtags $\leq$ tolerance
- Riolo *et al.* (*Nature*, 2001) showed that tag-based altruism can evolve; Roberts & Sherratt (*Nature*, 2002) claimed it would not evolve under more realistic conditions



Spector, L., and Klein, J. Genetic stability and territorial structure facilitate the evolution of tag-mediated altruism. In *Artificial Life*.

Evolutionary Computation



Genetic Programming

- Evolutionary computing to produce executable computer programs.
- Programs are tested by executing them.

Evolving Modular Programs

With "automatically defined functions"

- All programs in the population have the same, pre-specified architecture
- Genetic operators respect that architecture
- Complicated, brittle, limited...
- Architecture-altering operations: more so

Evolving Modular Programs

With "execution stack manipulation"

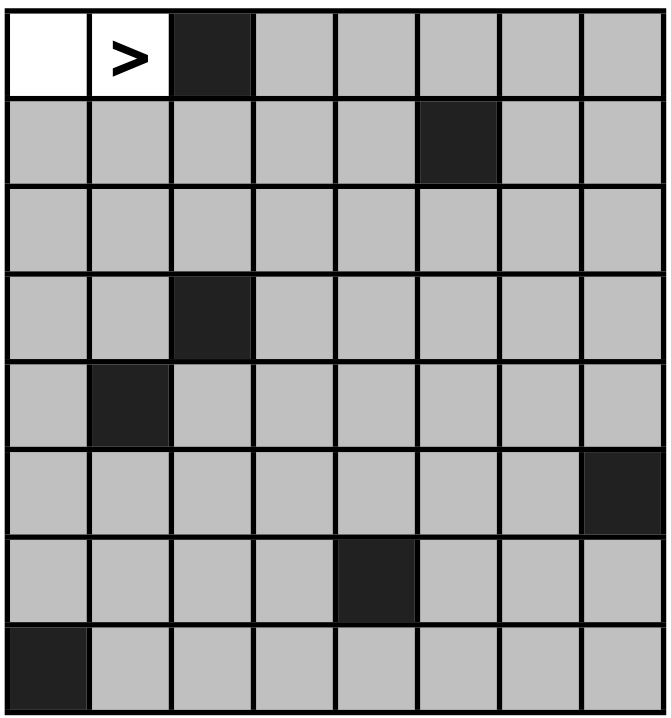
- Code queued for execution is stored on an "execution stack"
- Allow programs to duplicate and manipulate code that on the stack
- Simple types and uses of modules can be evolved easily
- Does not scale well to large/complex systems

Evolving Modular Programs

With tags

- Include instructions that tag code (modules)
- Include instructions that recall and execute modules by *closest matching* tag
- If a single module has been tagged then all tag references will recall modules
- The number of tagged modules can grow incrementally over evolutionary time

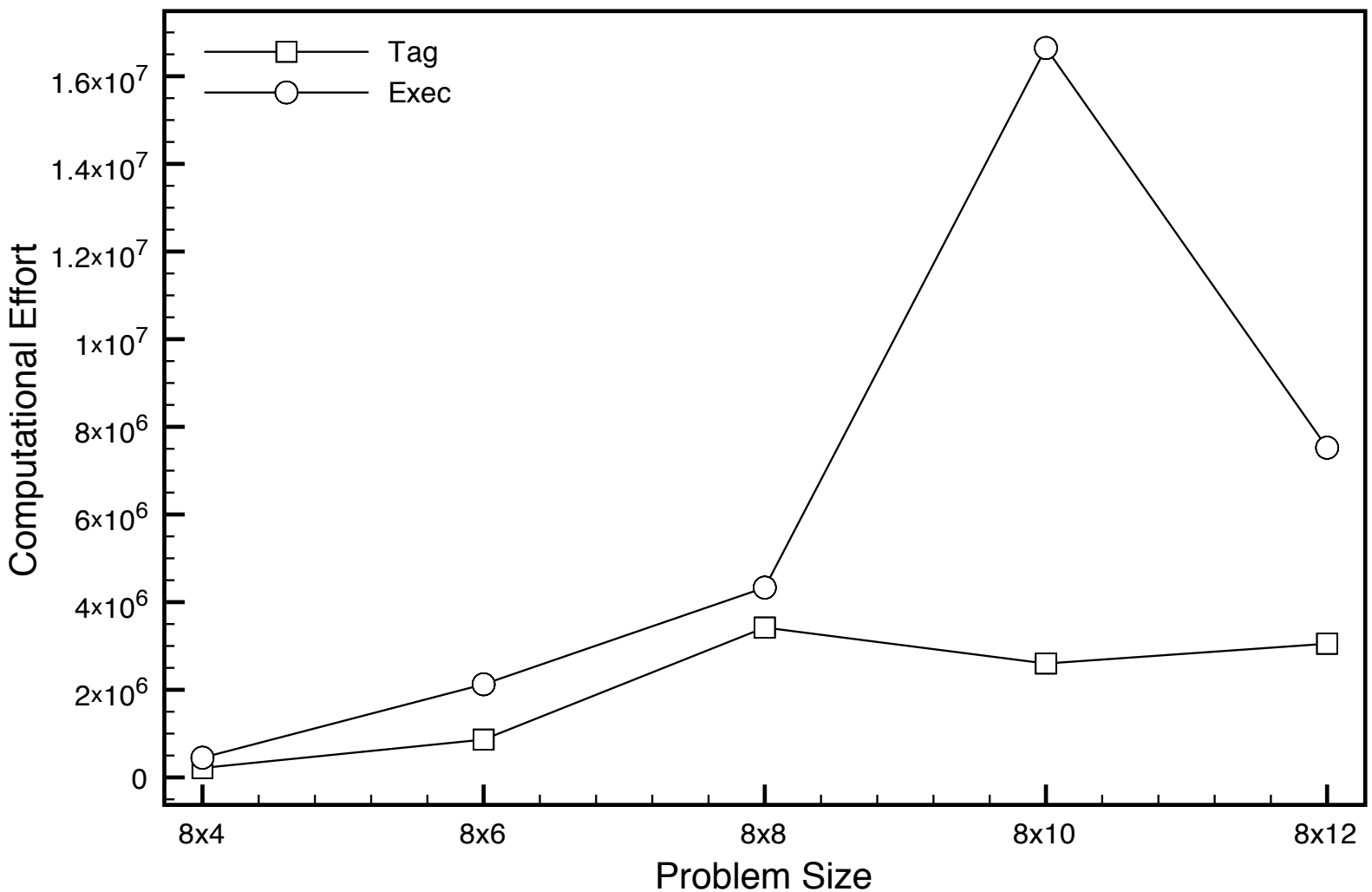
Dirt-Sensing, Obstacle-Avoiding Robot Problem



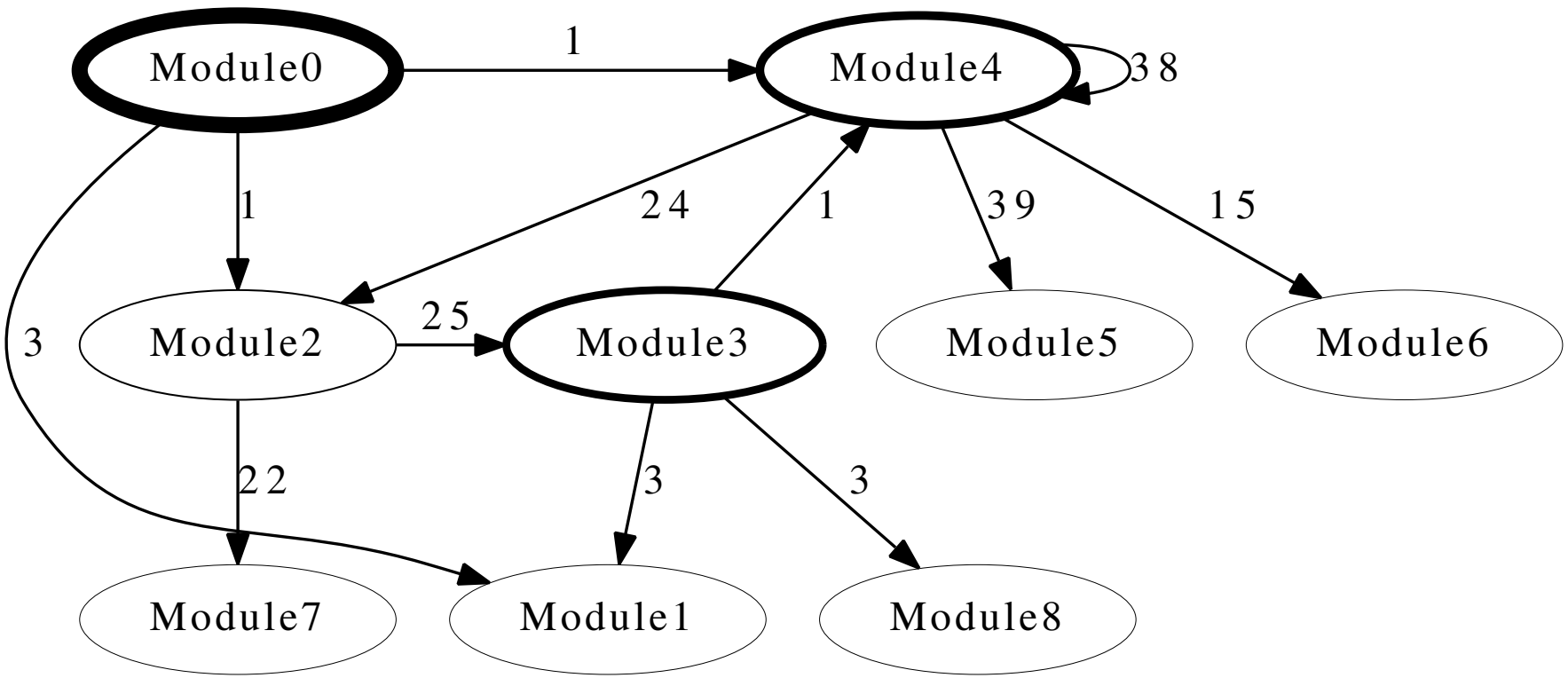
DSOAR Instructions

Condition	Instructions
Basic	if-dirty, if-obstacle, left, mop, v8a, frog, $\mathcal{R}_{v8}$
Tag	if-dirty, if-obstacle, left, mop, v8a, frog, $\mathcal{R}_{v8}$, tag.exec.[1000], tagged.[1000]
Exec	if-dirty, if-obstacle, left, mop, v8a, frog, $\mathcal{R}_{v8}$, exec.dup, exec.pop, exec.rot, exec.swap, exec.k, exec.s, exec.y

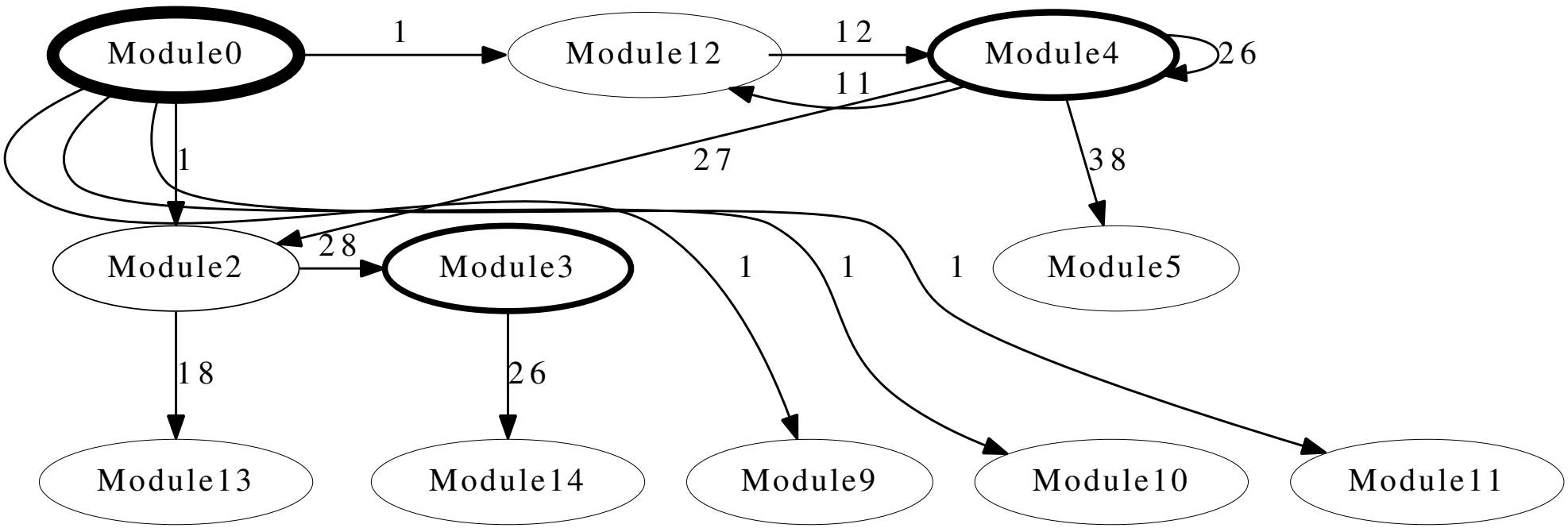
DSOAR Effort



Evolved DSOAR Architecture (in one environment)



Evolved DSOAR Architecture (in another environment)



Conclusions

- Tags provide an effective mechanism for the evolution of modular programs that solve difficult problems
- Tags may provide or explain mechanisms that support the evolution of modularity in a range of other systems, both natural and artificial