The Philosophy of Computer Simulation

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The Scope and Limits of Computer Simulation

What are they?

The Fundamental Property of Computation:

Universality

All ordinary programming languages

- are Universal Turing Machines
- can be programmed to simulate *any* (computable) function

Computer Simulation?

- Flight simulators
- Simulated sex
- Game simulations

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Only the simulated . . . ologies are of interest here. . .

Is there a serious science without simulation studies today?

Simulation

A common definition —

> *Simulation:* The use of a computer to solve an equation that we cannot solve analytically.

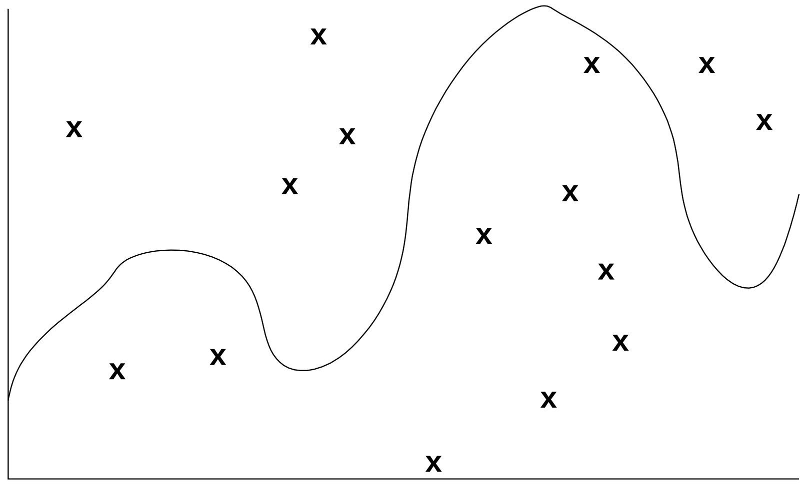
– e.g., Humphreys (1991), Frigg & Reiss (2007)

This includes both too much and too little.

Simulation

Too much:

- Monte Carlo integration:



Simulation

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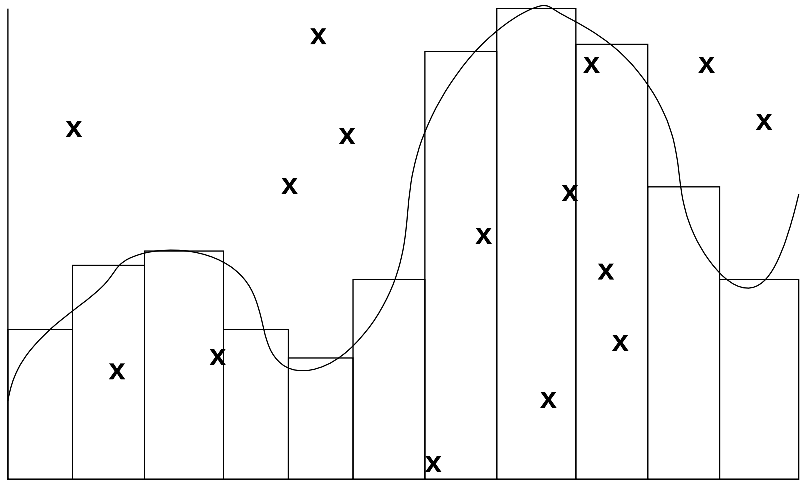

and numerical quadrature?

…and so also all numerical computation!

- Also, simulated sex.

Simulation

Too little:

- Analysable simulation: If an equation/process becomes analysable, it is no longer simulable?
  - This is absurdly subjective.
- Non-equation oriented simulation: ALife often has target processes without target equations

Simulation should instead be defined in terms of methodological role…

Simulation

A better definition —

> *Simulation:* A process which mimics the relevant features of a target process.
>
> – Hartmann (1996)

This definition corresponds to actual practice:

- ALife simulation
- Allows for the “experimental side” of simulation: meaningful interventions

Bold Simulation

Simulation surge ⇒ philosophy of simulation surge

Especially, bold philosophy of simulation:

1. Winsberg: Simulation is a new scientific method, requiring a new epistemology
2. Di Paolo et al (2000), Bedau (1999): Simulations are super thought experiments
3. Oreskes et al (1994): Simulation studies have no empirical content

The Fundamental Question of Simulation:

Is simulation an empirical method or not?

Simulation Definition II

S is a **Simulation** of P if and only if

1. P is a physical process or process type
2. S is a physical process or process type
3. S and P are both correctly described by a dynamic theory T containing (for S; parenthetically described for P):
    - an ontology of objects O_S (O_P) and types of objects $\Psi_i(x)$ $(\Phi_i(x))$
    - relations between objects $\Psi_i(x_1, \ldots, x_n)$ $(\Phi_i(x_1, \ldots, x_n)) \Rightarrow$ hence, states of the system, s

Simulation Definition II

3. (cont'd)

- dynamical laws of development (possibly stochastic): $f_S(s) = s'$ $(f_P(s) = s')$

I.e., P and S have a true common theory.

S is a **Computer Simulation** iff it is a simulation and a computer process.

Symmetry

Note the symmetry of my definition:

> We could just as well use the sun to simulate our astrophysical programs
>
> as use our programs to simulate the sun

What stops us?

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What stops us? Ronald Giere’s (Borge’s) map metaphor:

- Suppose we had a gigantic 3-dimensional map of the earth, just as big as the earth!
- Then we could measure distances, etc with perfect accuracy!!

Homomorphism

So, we require that our simulations *not* be as detailed as the processes we simulate, both for theoretical and for practical reasons. Instead:

> There should exist a **homomorphism** h from P to S

Homomorphism

A **homomorphism** h from P to S: a mapping $h : P \to S$ such that

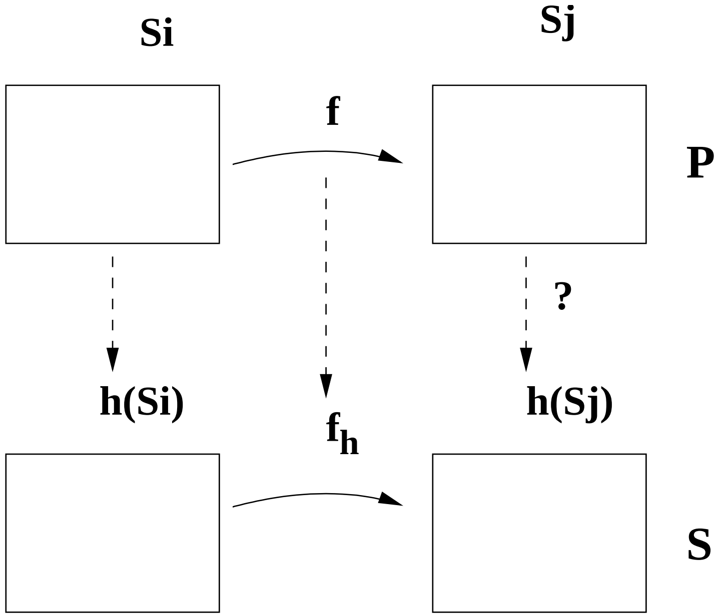
1. For every object $x \in O_P$, $h(x) \in O_S$.
2. For every relation Φ, $\Phi(x_1, \dots, x_n)$ is true of P iff $h(\Phi) = \Psi$ and $\Psi(h(x_1), \dots, h(x_n))$ is true of S
3. For every state transition function f in P, $f(s) = s'$ iff $f_h(h(s)) = h(s')$
   (or, adjusted, for stochastic laws)

(NB: This is an ideal!)

Validation

How do we know when a simulation is adequate?

"Validation": We can validate (test) a simulation S for adequacy against a system P, given a mapping $h : P \rightarrow S$ by testing whether h is a homomorphism:



Homomorphism

The existence of a(n approximate) homomorphism is *crucial*

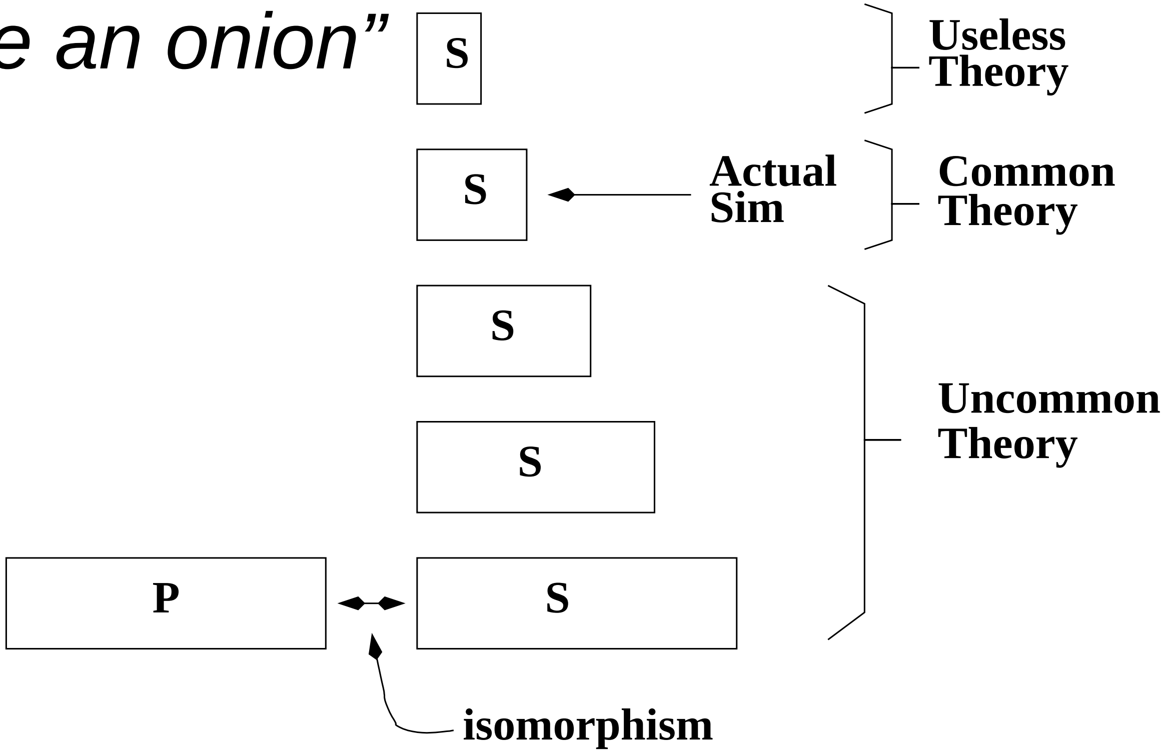
> it underwrites the relevance of the simulation for the system being simulated.

The level of resolution of the homomorphism (simulation) depends upon two major points:

- How well do we (think we) understand P? How detailed a theory do we have to test?
- Pragmatic constraints upon our simulation (e.g., how much time can we spend waiting).

Shrek’s Theory of His Simulation

“I’m like an onion”



Computer Simulation?

What supervenience is not:

- Reduction

What supervenience is:

- Multiple Realizability
- Instantiation
- Emergence

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Candidate examples:

- Minds: humans, Martians, robots
- Life: Earth biology, exobiology, virtual biology
- Global warming: Venus, Earth, Hell

Simulation as Thought Experiment

Di Paolo et al (2000) and Bedau (1999):

- Thought experiments can *draw out* implications of a theory, revealing
  - contradictions
  - possibilities

Simulation as thought experiment implies:

Simulation is purely deductive, non-empirical, exploration of theoretical consequences
See also Oreskes et al (1994) and many others.

Simulation as Substitution for Thought Experiment

Di Paolo et al

- Thought experiments are transparent

  They gain their power from their pellucidity

- Simulations are opaque

We use simulations when thought experimentation is inaccessible

since the outcome is inaccessible, this has the flavor of experimentation, potential for surprise

Thought Experiments as Opaque

What are Thought Experiments?

Examples:

- Maxwell’s Demon
- Einstein-Podolsky-Rosen Paradox
- Frank Jackson’s Knowledge Argument
- Ned Block’s Chinese Brain

Dennett’s Response:

> Thought experiments are figments of the imagination!

Simulation as Thought Experiment

So, perhaps this thesis really means:

simulations are idle!

But

- the evidence of widespread utility of simulation means something

Epistemology of Simulation

Two acknowledged steps:

Verification: Determine whether the sim correctly implements the theory being investigated.

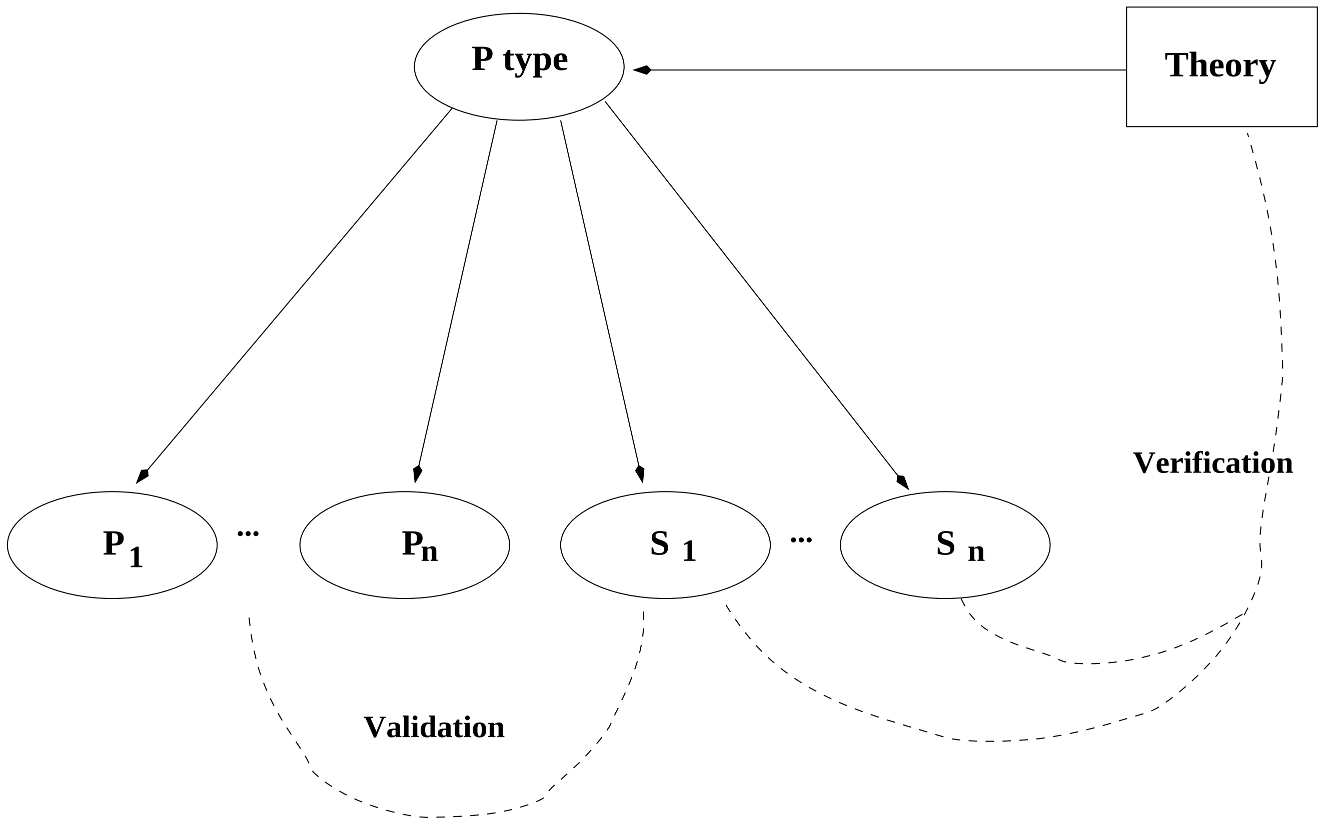
- Design verification, debugging, consistency checks

Validation (Confirmation): Determine whether the sim as implemented conforms to the target

- Set initial conditions; run the sim; generate novel predictions; compare with reality

Epistemology of Simulation

Epistemology of simulation = epistemology of experiment



The Failure of Simulation

There are many places where this confirmation process can break down. E.g.,

- Debugging
- Wrong initial conditions
- Wrong theory implemented
- Inaccessible predictions: if we can only retrodict, can we trust our sim?

The first three lead to disconfirmation; the last to distrust

The Failure of Real Experiment

There are analogues to each of these failures in real-world experimentation:

- Debugging/wrong initial conditions: Lead to incorrect prediction
- Wrong theory: Leads to incorrect prediction
- Inaccessible predictions: if we can only retrodict can we trust our theory?
  - Not if our theory is manufactured to fit the existing data

The Failure of Real Experiment

But at least when you’re testing the real-world you know what you’re testing is *real*! You can’t be testing the wrong thing!

The Failure of Real Experiment

But at least when you're testing the real-world you know what you're testing is *real*! You can't be testing the wrong thing! *Wrong.*

Real experimentation *is* simulation:

- Rat simulates human
- Subpop simulates target pop
- Observed/prodded phenomenon simulates unobserved

⇒These go wrong the same ways as computer simulation!

Early Theory Testing

Given

- A phenomenon of interest
- Competing potential explanations
- Lack of data/experimental options for testing

Simulation can

- Find a range conditions needed to realize each theory
- Subsequent research can test for such conditions

A kind of “proof of concept”

generating also criteria for confirmation

An Example Simulation

The Evolution of Aging (with O Woodberry & A Nicholson)

Weismann (1889): aging is adaptive via group selection

> aging releases resources to the young, making
> the group more viable

⇒ Response: Group selection is mysterious, given individual fitness as the driver of evolution.

Evolution of Aging

Non-adaptive theories of aging evolution:

- Medawar (1952): mutation accumulation.
- Williams (1957): antagonistic pleiotropy.

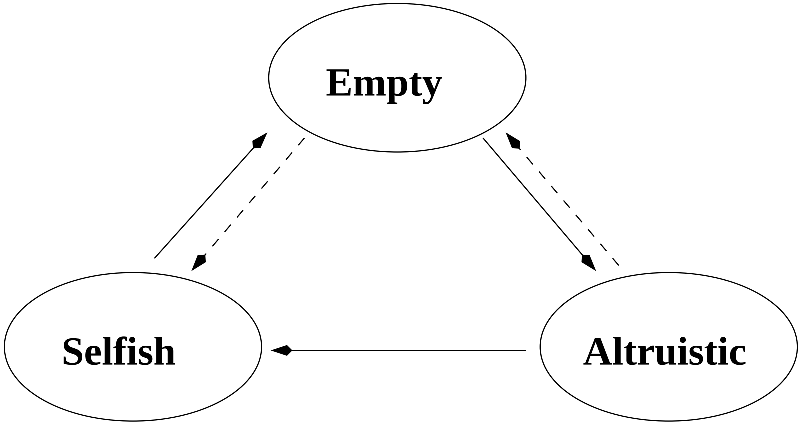
Experiment has undermined these theories in the meantime

- Experimental increase in longevity in flies comes with a fitness reward, not cost (Leroi et al, 1994)
- Caloric restriction reduces aging rate, with no fitness cost (Weindruch and Walford, 1986)

Group Selection

Group selection (of altruism) has been vindicated since Weismann, at least as a live possibility.

- Maynard Smith (1976) laid out conditions for it to occur: expected number of seeding migrations out of selfish groups must be less than 1



Group Selection

Price (1970) and Hamilton (1975) analyse this in terms of

- Positive associations between group fitness and the trait being selected
- Group benefit must outweigh individual harm of altruistic gene

An Example Simulation

- Group selection occurs more readily given within-group kin selection (Woodberry et al, 2005)
    - Kin selection provides a mechanism for altruism to evolve, stabilize within groups.
    - When kin selection was turned off in a replication of Mitteldorf's (2004) group selection simulation, group selection fell over.
    - Kin selection and group selection are not antagonistic. (Cf. Multilevel Selection Theory, Foster et al, 2005)

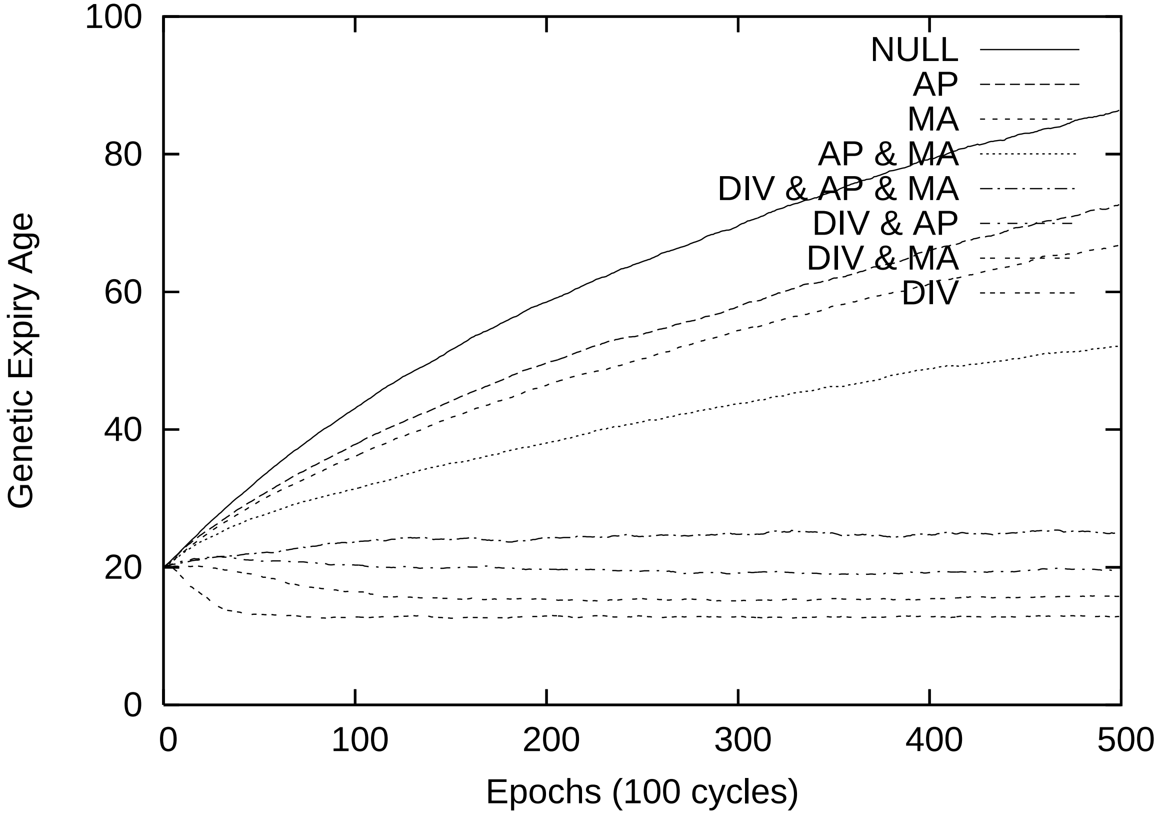
An Example Simulation

Our simulation is an evolutionary ALife simulation with (Woodberry et al, 2007)

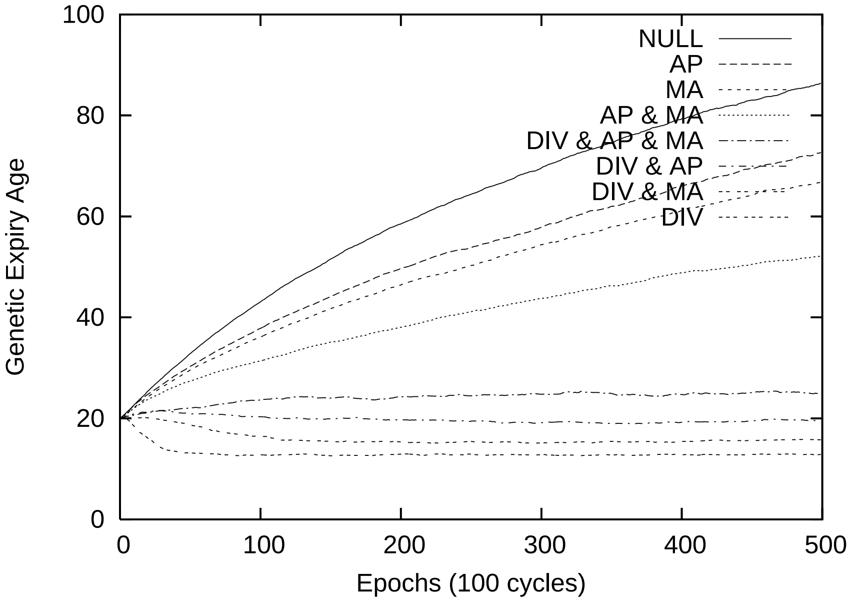
- Host population: aging rate; vulnerability string
    - In semi-isolated reproductive groups
- Disease population:
    - transmit probabilistically by close matches to neighbors' vulnerability strings
    - reproduce using host energy

An Example Simulation

Result: aging rate evolution, as a defence against disease.



An Example Simulation



- Intra-group aging rates evolve via kin selection
- Groups with higher turnover have higher diversity, greater health, lower extinction rates

A partial vindication of Weismann

A Possible Simulation

The complete neurophysiology of some human…

Conclusion

Certainly, running a simulation is not the same thing as running a real-world experiment.

- Confirmation requires actually looking at the real world.
  - Checking for matching initial conditions
  - Checking for matching outcomes

This is the very same kind of supplementation that predictive use of theories require.

Conclusion

There is this asymmetry:

- Simulation without the real world (without confirmation) is pointless
- Experimentation without simulation has been pointed for hundreds of years already

Still,

> There is nothing new here under the epistemological sun; there is plenty that is new methodologically, however.

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