

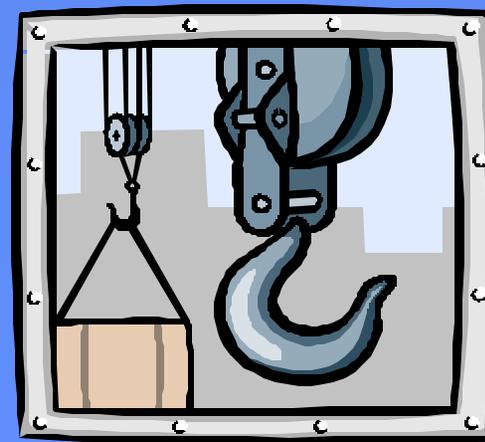
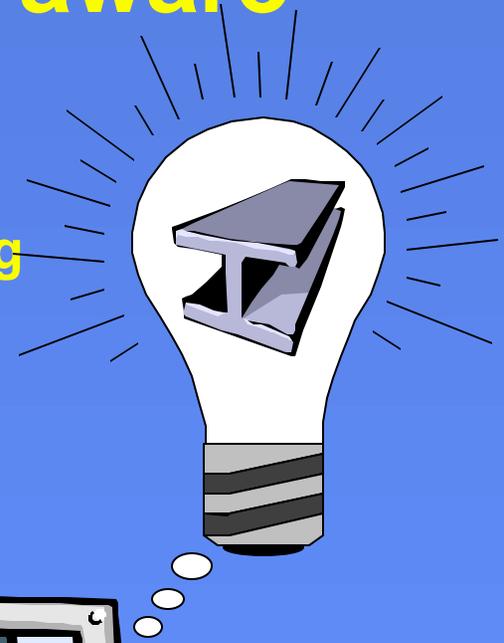
Embedded Intelligence: Bizarre Systems for the Steel Industry



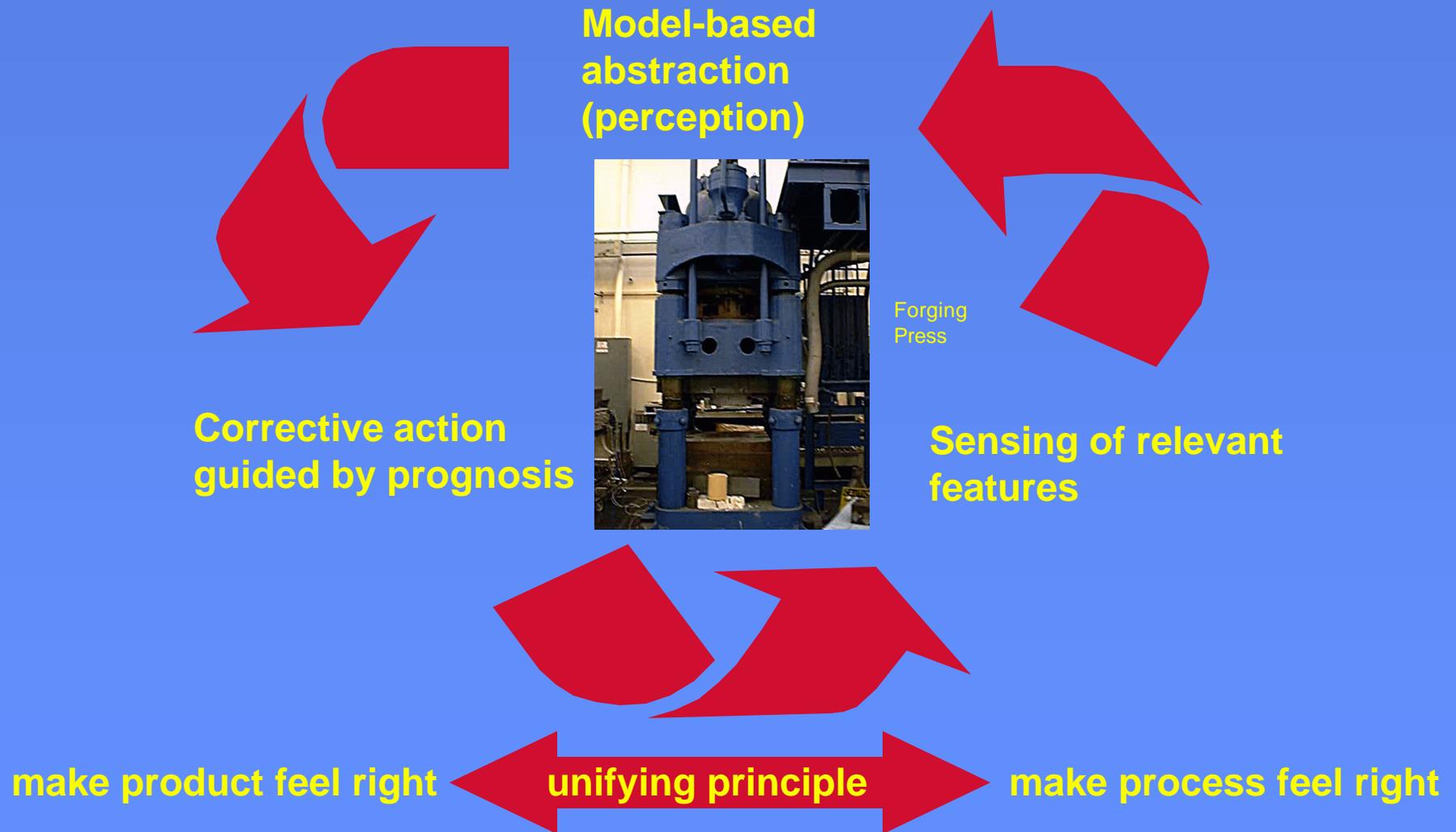
Prepared for
2000 AISE Annual Convention
Dr. Stephen W. Kerchel
ORNL - Instrumentation and Controls Division
September 12, 2000

Steelmaking processes of the near-future will be self-aware

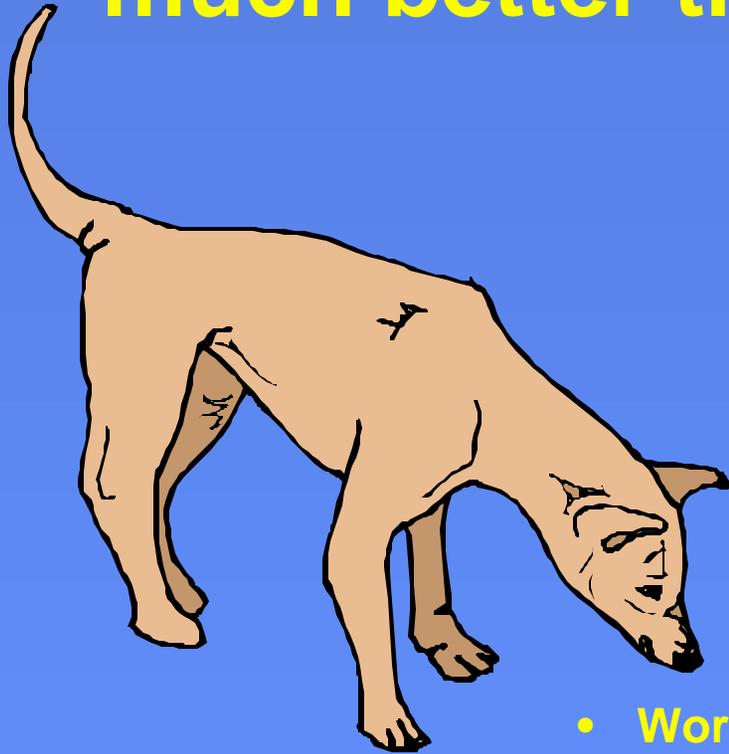
- Abstract sensor streams into feeling
- How does the product feel?
- How does the process feel?
- What do I do to feel good?
- What is my function?



These self-organizing processes will work like metabolism and repair in biology



For many decisions, brains are much better than computers

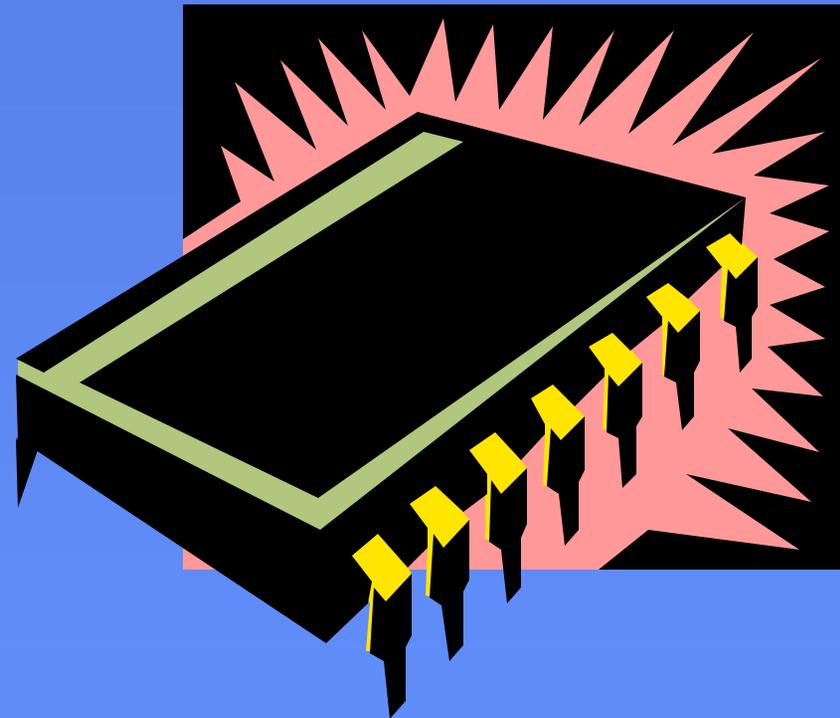


- **World's best security detector**
 - A trained dog
- **Can widgets do better?**
 - Faster
 - Massively parallel

Brains are a million times slower than chips

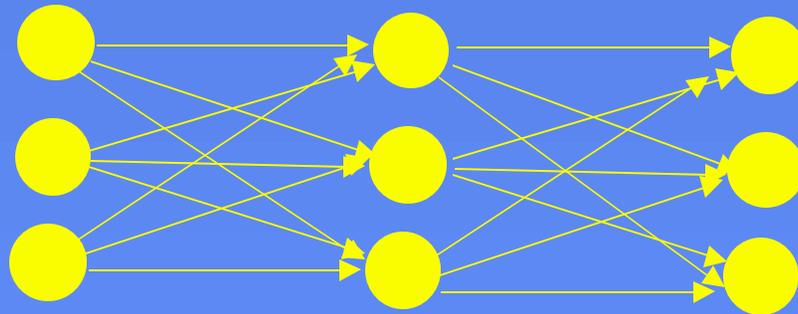


milliseconds

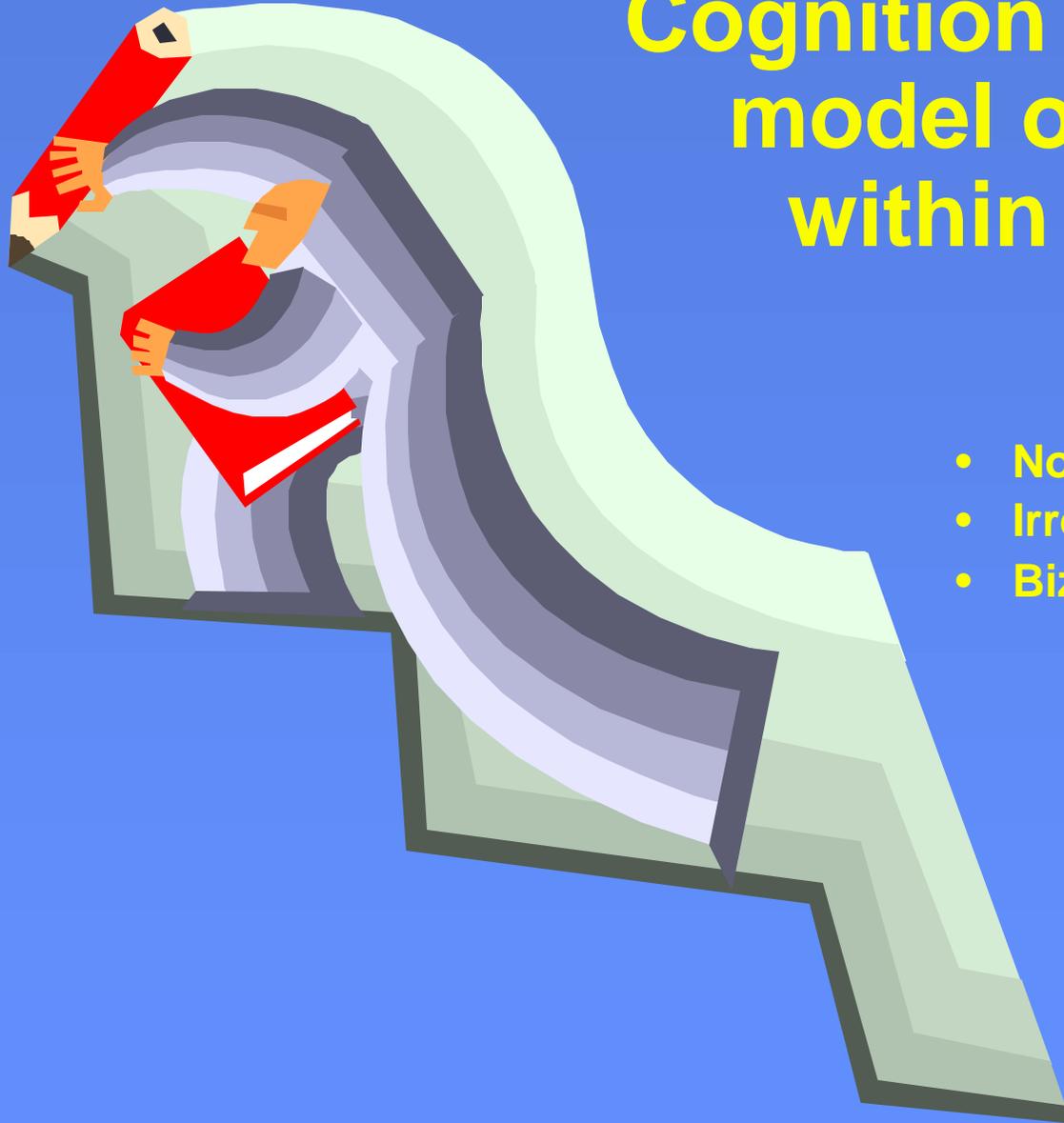


nanoseconds

Massive parallelism creates factorially many interfaces



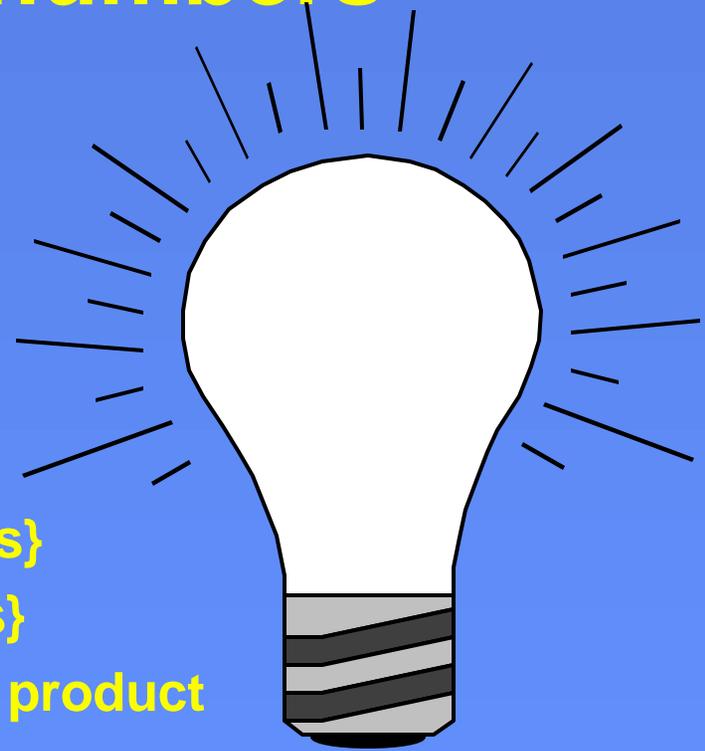
Cognition carries a model of itself within itself



- Non-Turing Computable
- Irreducible to Numbers
- Bizzare but not Absurd

The common idea:
descriptions of non-bizarre behaviors
are *reducible*
to lists of real numbers

- $f: P \rightarrow R^n$
- $P = \{\text{process states}\}$
- $R = \{\text{Real numbers}\}$
- $R^n = \text{nth Cartesian product}$



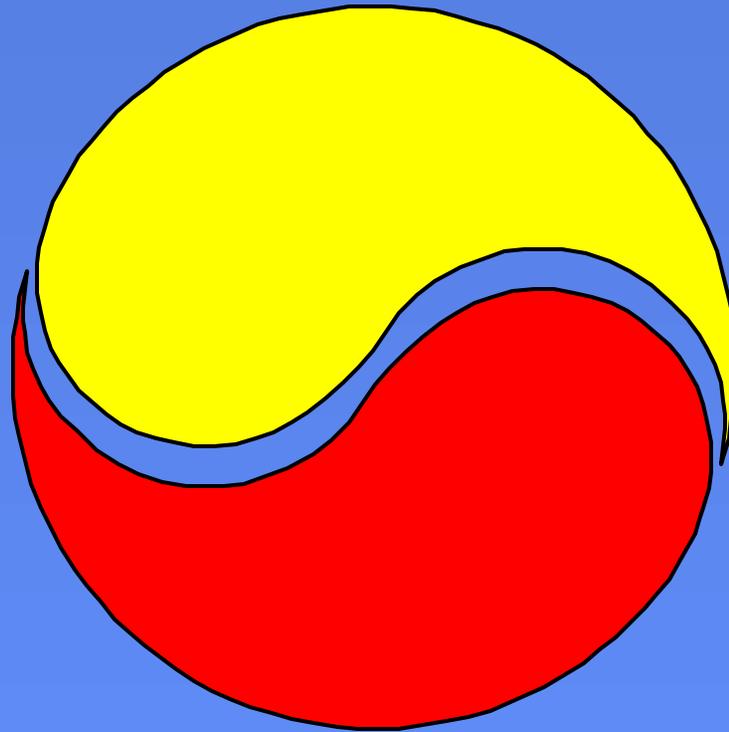
Given that bizarre *does not* mean absurd, what logical conclusion can we draw about bizarre systems?

$((\text{not bizarre}) \Rightarrow \text{reducible})$

\Leftrightarrow

$((\text{not reducible}) \Rightarrow \text{bizarre})$

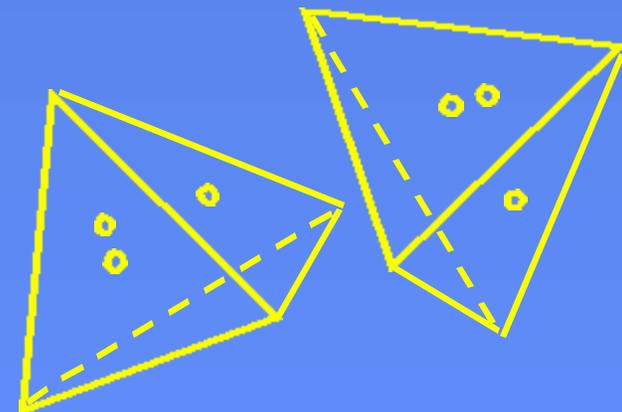
Entanglement is bizarre behavior



- Predicted by quantum mechanics
- No classical analog
- Self-referential/impredicative
- Incomputable
- *Is observed in reality*

To appreciate what a truly bizarre behavior might look like in the macro world, imagine a pair of “magic dice”

- Each die is fair
 - Four outcomes per die
 - $p = 0.25$
 - for any toss of either die
- The pair is rigged
 - Toss both at once
 - $a = 1 \text{ or } 4 \iff b = 2 \text{ or } 3$
- If I know “a,” I can tell “b”
- Behavior is *entangled*



The “magic” is inherent in the relationship between the parts



- If I know “a,”
- I can tell “b”
- Must observe pair (no entangling part)
- *Reduction* to individual dice ignores entanglement
- Ignoring it won’t make it vanish
 - it is no less real
 - because it is irreducible

**We can infer properties for one element
by observing another remotely, and
*there is no connecting part!***

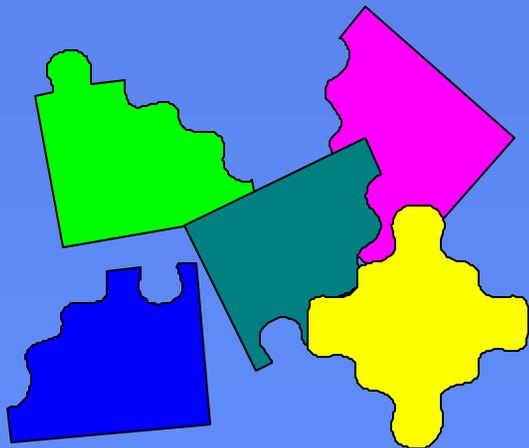


- Each part behaves as intuitively expected
- System behaves counterintuitively
- Reduction ignores something crucial in reality

Now, that's bizarre!

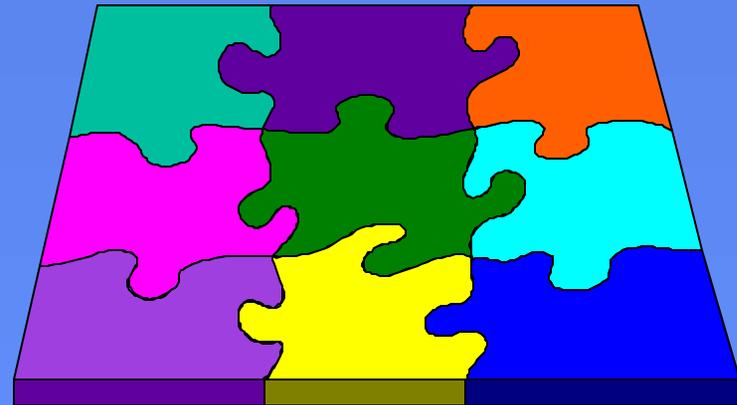
Entanglement is bizarre, not because it contradicts reality, but because it violates intuition

We see this...



Our model of reality

... instead of this



Underlying reality

- Our inability to perceive directly or intuitively
- Does not eliminate a causal connection

Causality is the proposition that effects or events in reality have causes



Why this effect (phenotype)?

- Material cause (input)
- Efficient cause (transforming relationship / transfer function)
- Formal cause (genotype)
- Final cause (purpose)

In a simple (reducible or mechanistic) system ($P \rightarrow R^n$) causes are distinct and unentangled



Why this effect?

- Material cause (initial conditions)
- Efficient cause (constraining dynamical law)
- Formal cause (genotypical parameters)
- Final cause (there isn't any)

Ignoring an aspect of reality does not make it vanish



- Epicycles ignored force/energy
- Cartesian reduction ignores relationships

Can we rationally describe the relational aspect of reality?



- **Mathematical models**
 - Traditionally used only to count pieces
 - However, they can encompass relationships

A mapping between entailments is more general than a mapping between lists of numbers

Function:

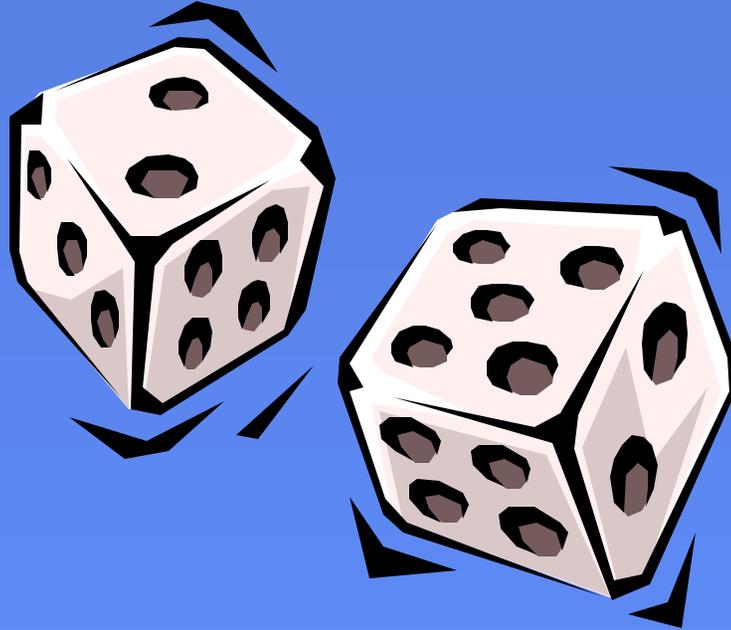
$y = f(x)$
 $y \Vdash Y$
 $x \Vdash X$
 $f: X \rightarrow Y$

Category:

$z = g(y), y = f(x)$
 $z \Vdash Z, y \Vdash Y, x \Vdash X$
 $h: X \rightarrow Z$
 $h = F(g, f)$

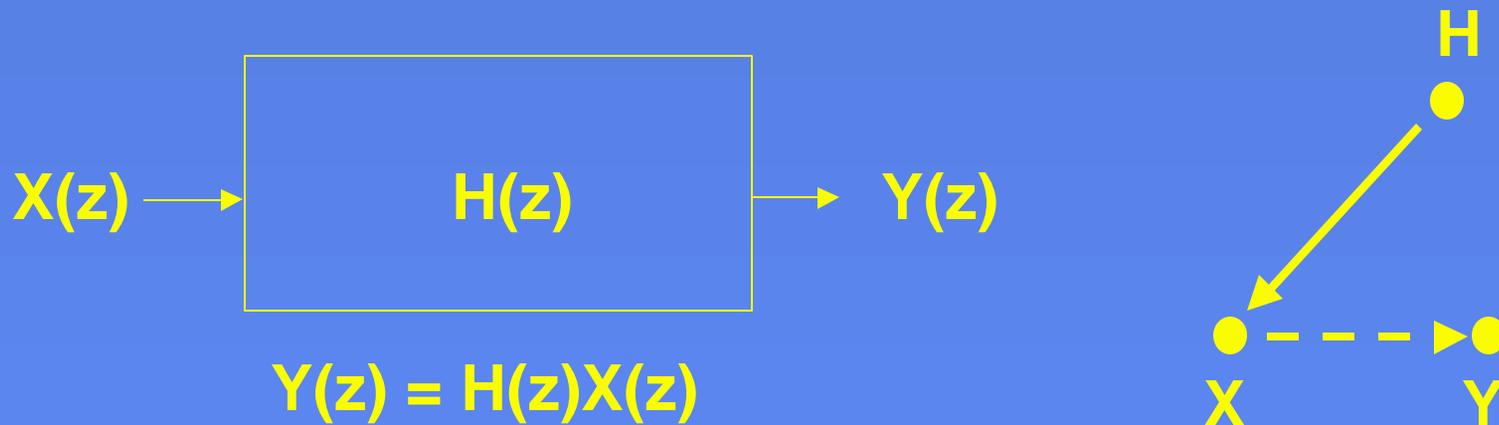
- Inferences can be drawn from either mapping
- One just as logical as the other
- Categories accommodate impredicativities
- Can address unquantifiable relationships

Impredicative behavior cannot be reduced to a list of numbers



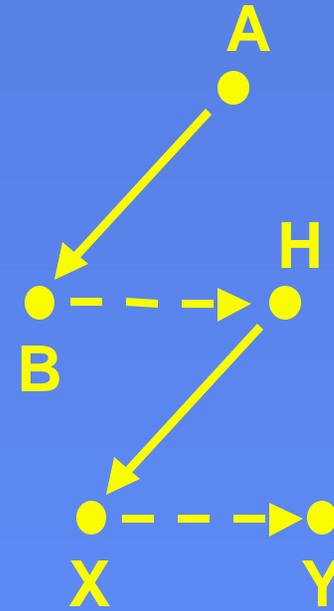
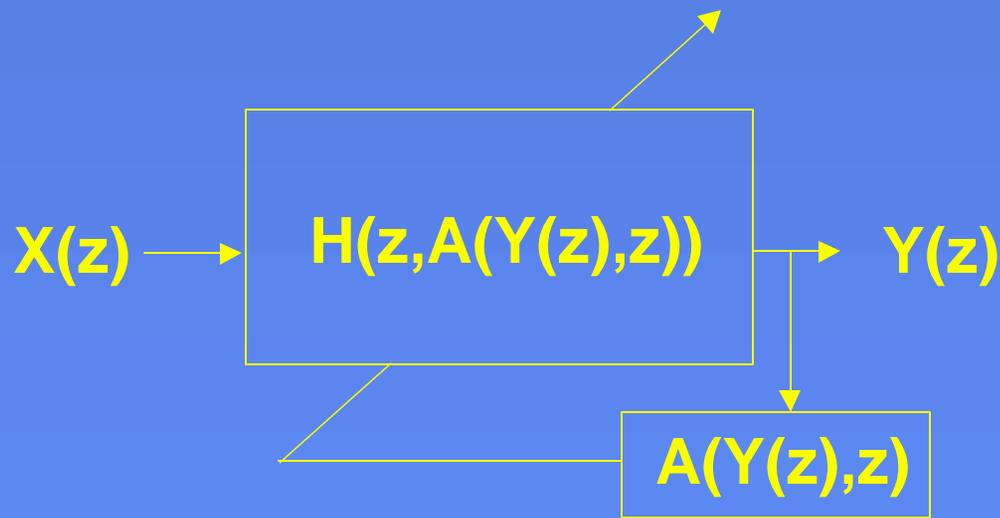
- A system of magic dice is irreducible
- Considering either die alone ignores relationship
- Relationship inherent in structure of reality
- Ignoring it does not make it vanish
- Relationship not captured as a number
- Inferential entailment corresponding to causal entailment

To appreciate causal entailment, consider a LTI digital filter

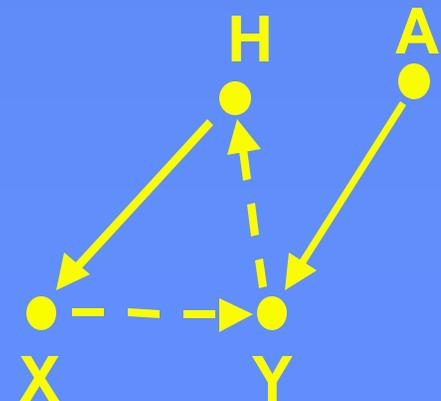


- H entails X-Y relation
- What causes the output (effect), $Y(z)$?
 - Input data (material cause), $X(z)$
 - System transfer function (efficient cause), $H(z)$
- But, what causes $H(z)$; why this function?
 - The Hand of Man
 - Unentailed from within the system

We can design an adaptive filter, one that updates its own transfer function



Let $B = Y$



- Entailment, H, is itself entailed
- What causes H(z), (effect)?
 - Material cause, Y(z)
 - Adaption algorithm (efficient cause), A(Y(z),z)
- But, what causes A(Y(z),z); why this function?
 - The Hand of Man
 - Unentailed from within the system

Can we appeal to biology to find a constraint to stop the infinite regress?



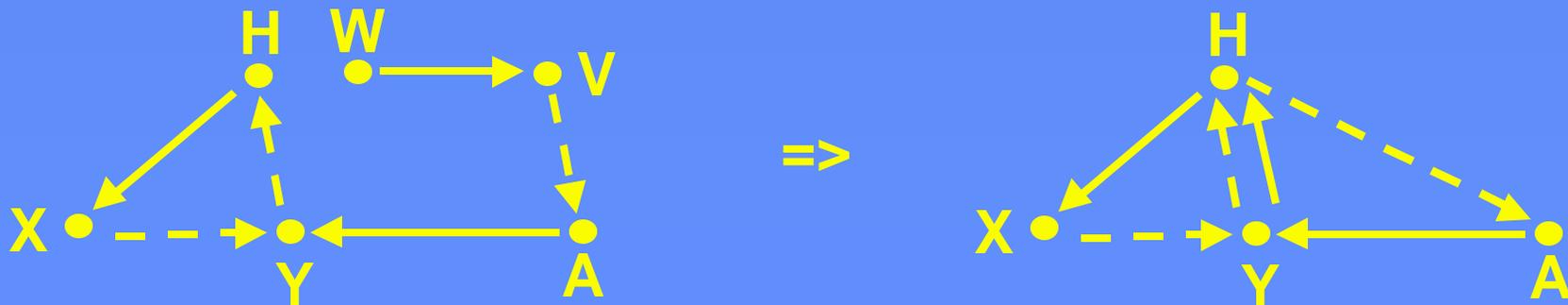
I/O process (metabolism)



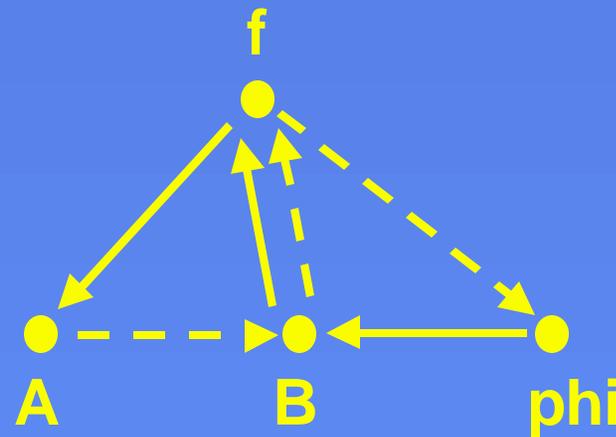
Adaption process (repair)



Entailment of adaption (replication)

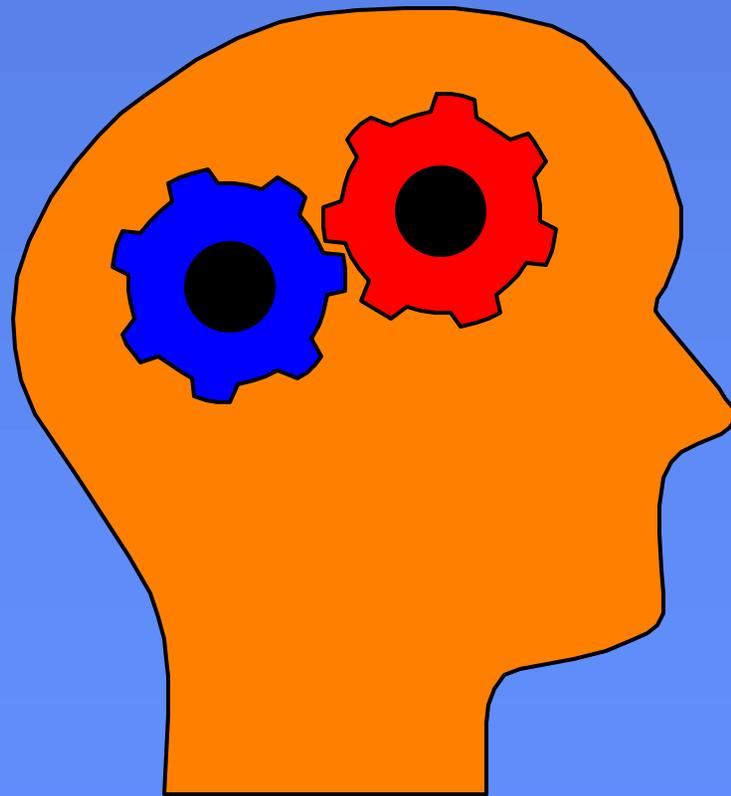


Organisms can be distinguished as a category of bizarre systems closed to efficient cause



- Simplest organism: repair subsumes replication
- Everything internally caused, except input, A
- Every entailment is entailed within the system
- Life is self-referential
- Infinite regress of causal entailments not required
- Causalities are entangled and inseparable

**Processes of mind are observed to
have the same self-referential
property as processes of life**

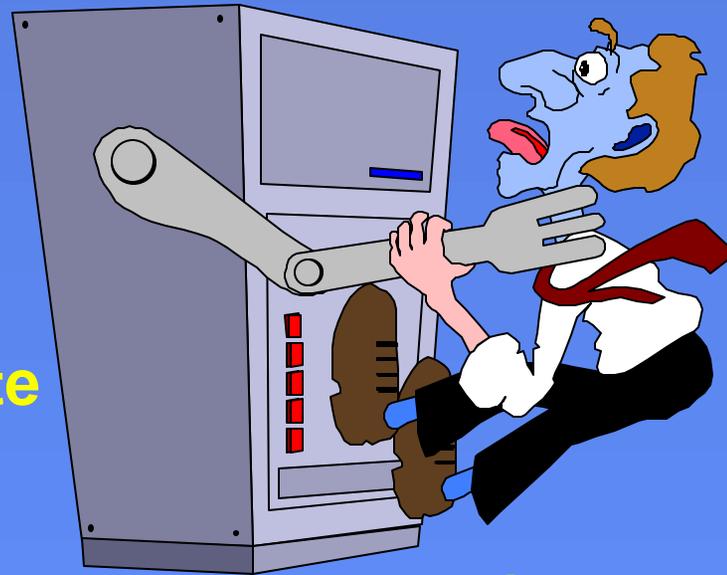


Have we made an artifact that abstracts meaning? Probably not

Turing Computable:
(Finite algorithm of finite instructions)

=>

Purely syntactical
Finally reducible
(life and consciousness
not reducible)



Life/consciousness:
(self referential)
inherently
vulnerable to
incomputability

Could the Hand of Man make a
semantic (extracts meaning)
artifact? Yes... ,



... if we can make a

complex,

living,

conscious artifact

(much more than a
reduced, or syntactic, simulation)

What's holding us back is technology --- not fundamental or theoretical limits

- A bizarre artifact must behave bizarrely
 - Irreducible => Functional components, instead of parts
 - Might need to grow rather than build



Entanglement *might* serve
as a material cause

If you can grow a system to make stuff, why not grow the stuff directly?



- Know makeup of stuff
- Design organism to make stuff
- We're already doing the inverse
 - Bioremediation
 - Design bug to destroy stuff
 - » Noxious chemicals
 - » Explosive residues

Bizarre systems will revolutionize the steel industry



- **Bizarre behavior**
 - Impredicative \leftrightarrow self-referential
 - Entangled \leftrightarrow context-dependent
 - Irreducible, incomputable, but tractable
- **MR \leftrightarrow self-regulation/repair**
 - Self-aware continuous caster (sooner)
 - Grow parts to spec (later)