# Can Computation Give Rise to Meaning?

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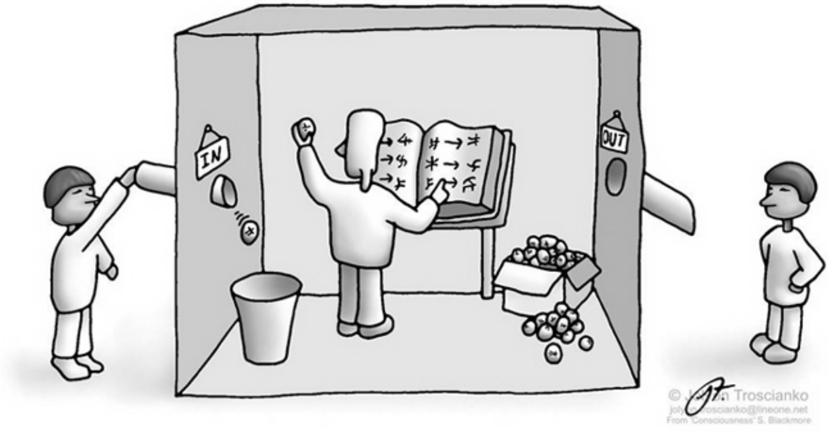
- Turing (1950): Check it out.
  - Imitation game
  - Semantics as verbal behavior
- Searle (1980): No.
  - Computation is purely formal (syntactic)
  - We need the right stuff (brain) to cause semantics
- Rapaport (1986): Yes.
  - This is not a wetware/hardware problem
  - Program qua algorithm does not understand, but the running process does

# Searle-in-the-box: Chinese Room




The original thought experiment is Rogers (1959)

- CR is an ill-thought experiment: No grammar can be turned into a look-up table of forms and fit into a finite-size room. Bozsahin (2006, 2012)

  Rey (1986); Rapaport (2006)
- If humans only exchanged forms like CR, they could not learn meanings either
- They appear to triangulate forms with some verbal or bodily behavior and interaction

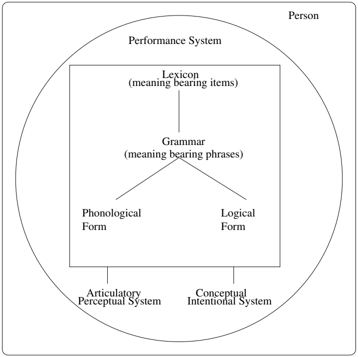
# Two channels in sensory impairments or experiential deprivation

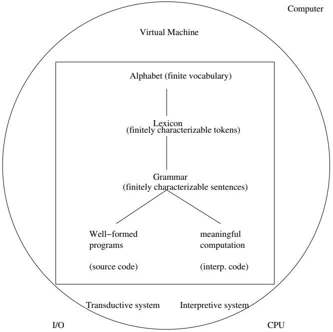
- Did Helen Keller learn to cause semantics? Rapaport (2006)

  "How Helen Keller used syntactic semantics to escape from a Chinese Room"
- Two channels of information:
  - forms
  - behavior, action, and observation (of the world, internal and external)

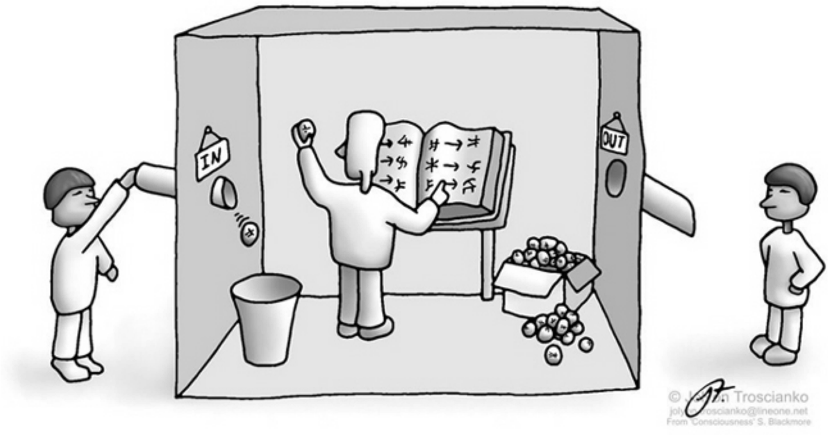
- Children with autism manifest soliloquy
- Blind children learn the difference between look and watch
  Landau and Gleitman (1985): you can touch the table but don't look at it!
- Deaf children acquire sign language (not gestures)
  **If** they are exposed to data in the critical period, just like other children

# Grammar, cognition and computation: bird's eye view

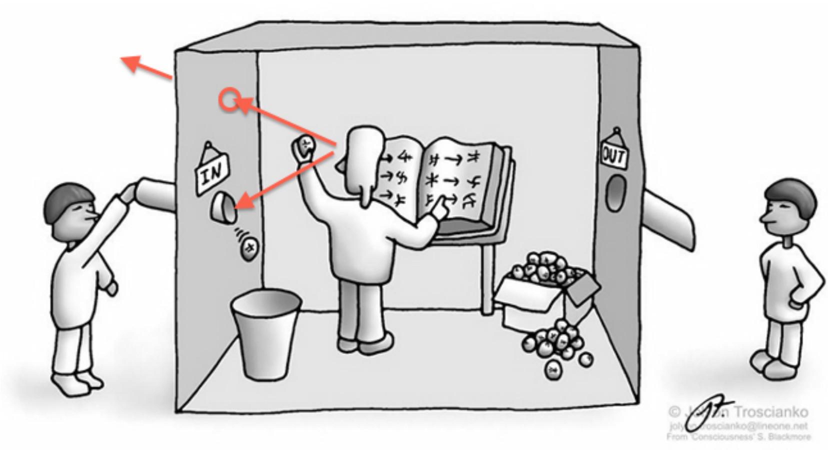


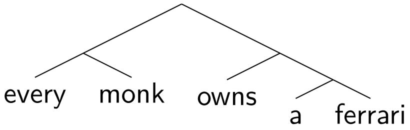
# Searle's Chinese Room

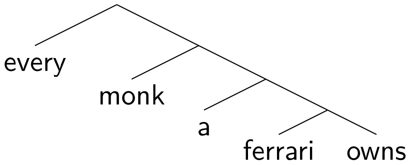


# The real Chinese Room



# Logician's view of: every monk owns a ferrari



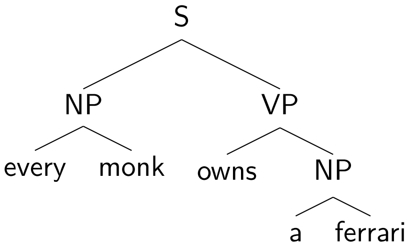



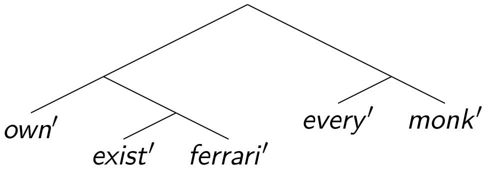

$$(\forall x)(monk(x) \rightarrow (\exists y)(ferrari(y) \wedge owns(x, y)))$$

$$(\exists y)(ferrari(y) \wedge (\forall x)(monk(x) \rightarrow owns(x, y)))$$

# Linguist's view

Heads of substantive phrases have lexical content

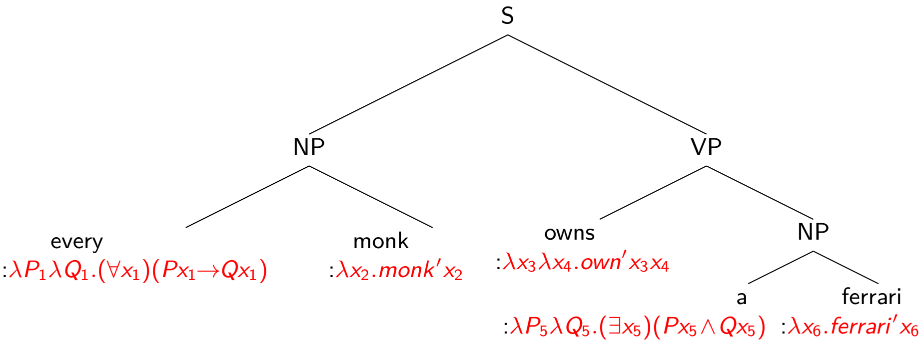



What are primes about?

# Computational Linguist's view

All head dependencies are efficiently computable

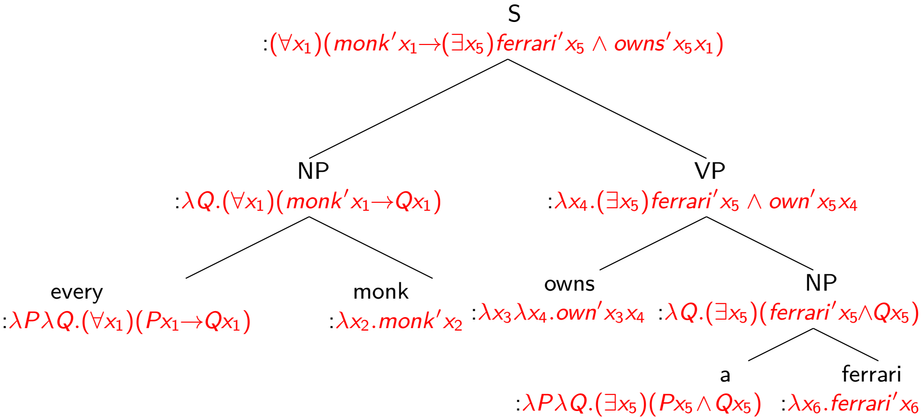



Where do primes come from?

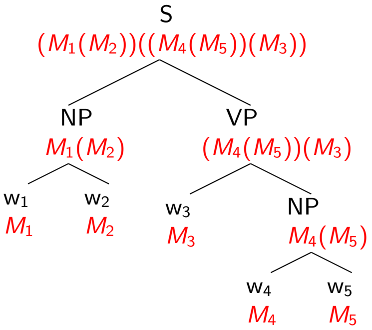
What causes semantics?

How does a word come to be about a prime?

# Projecting structure



# Meaning without lexical content of words




Lexical content cannot be predicted from grammar

# Meaning without grammar

every — *every′*

monk — *monk′*

owns — *owns′*

a — *a′*

ferrari — *ferrari′*

Structure of meaning cannot be predicted without a grammar

# Meaning from word-grammar

| | | | |
|---|---|---|---|
| S | $\rightarrow$ | NP VP | $S' = NP'(VP')$ |
| VP | $\rightarrow$ | V NP | $VP' = NP'(V')$ |
| NP | $\rightarrow$ | Det N | $NP' = Det'(NP')$ |

| | | | |
|---|---|---|---|
| Det | $\rightarrow$ | every | $Det' = \lambda P \lambda Q.(\forall x)(Px \rightarrow Qx)$ |
| Det | $\rightarrow$ | a | $Det' = \lambda P \lambda Q.(\exists x)(Px \wedge Qx)$ |
| N | $\rightarrow$ | monk | $N' = \lambda x.monk'x$ |
| N | $\rightarrow$ | ferrari | $N' = \lambda x.ferrari'x$ |
| V | $\rightarrow$ | owns | $V' = \lambda x \lambda y.owns'xy$ |

Top part projects, and bottom part initiates meaning (hence the dichotomy)

Can we predict structure and lexical content together?

A causal mechanism for expressible/expressed meanings

# Reducing a grammar to its lexicon without loss of structure

Every right-hand side has one symbol; such rules are functions looking from constituent's perspective

| | | | | | |
|---|---|---|---|---|---|
| S | $\rightarrow$ | NP VP | $S' = NP'(VP')$ | $NP{=}S/VP$ | $VP{=}S\backslash NP$ |
| VP | $\rightarrow$ | V NP | $VP' = NP'(V')$ | $V{=}VP/NP$ | $NP{=}VP\backslash V$ |
| NP | $\rightarrow$ | Det N | $NP' = Det'(NP')$ | $Det{=}NP/N$ | $N{=}NP\backslash Det$ |

Slashed cats: structure-equivalent combinatory categories (eqv. under substitution)

$NP{=}S/(S\backslash NP)$ $\quad V{=}(S\backslash NP)/NP$ $\quad NP{=}(S\backslash NP)\backslash((S\backslash NP)/NP)$

$Det{=}(S/(S\backslash NP))/N$ $\quad Det{=}((S\backslash NP)\backslash((S\backslash NP)/NP))/N$

$N{=}(S/(S\backslash NP))\backslash((S/(S\backslash NP))/N)$
$N{=}((S\backslash NP)\backslash((S\backslash NP)/NP))\backslash((S\backslash NP)\backslash((S\backslash NP)/NP)/N)$

We've got N, V, Det without a need for NP, VP or S rule

N, V, Det are the only lexical categories in the grammar!

| | | |
|---|---|---|
| S | $\rightarrow$ | NP VP |
| VP | $\rightarrow$ | V NP |
| NP | $\rightarrow$ | Det N |

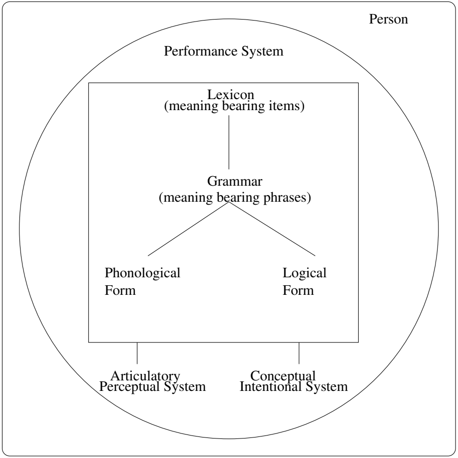
| | | |
|---|---|---|
| Det | $\rightarrow$ | every |
| Det | $\rightarrow$ | a |
| N | $\rightarrow$ | monk |
| N | $\rightarrow$ | ferrari |
| V | $\rightarrow$ | owns |

Two grammars capture the same structures and meanings:

| | | | |
|---|---|---|---|
| S | $\rightarrow$ | NP VP | $S' = NP'(VP')$ |
| VP | $\rightarrow$ | V NP | $VP' = NP'(V')$ |
| NP | $\rightarrow$ | Det N | $NP' = Det'(NP')$ |
| Det | $\rightarrow$ | every | $Det' = \lambda P \lambda Q.(\forall x)(Px \rightarrow Qx)$ |
| Det | $\rightarrow$ | a | $Det' = \lambda P \lambda Q.(\exists x)(Px \wedge Qx)$ |
| N | $\rightarrow$ | monk | $N' = \lambda x.monk'x$ |
| N | $\rightarrow$ | ferrari | $N' = \lambda x.ferrari'x$ |
| V | $\rightarrow$ | owns | $V' = \lambda x \lambda y.owns'xy$ |

| | | | |
|---|---|---|---|
| every | := | $(S/(S\backslash NP))/N$ | : $\lambda P \lambda Q.(\forall x)(Px \rightarrow Qx)$ |
| a | := | $((S\backslash NP)\backslash((S\backslash NP)/NP))/N$ | : $\lambda P \lambda Q.(\exists x)(Px \wedge Qx)$ |
| monk | := | $N$ | : $\lambda x.monk'x$ |
| ferrari | := | $N$ | : $\lambda x.ferrari'x$ |
| owns | := | $(S\backslash NP)/NP$ | : $\lambda x \lambda y.owns'xy$ |

Difference: in the red corner, form-meaning relation only through words




$$\text{owns} := (S\backslash NP)/NP : \; \lambda x \lambda y.owns'xy$$

Real semantics arising from computation is probably not

the proxy objects like *monk′*, *ferrari′*, *every′*

But the process of their construction.

# Learning veggies are veggies, eating is eating, plural is plural

Eat veggies.

possible hypotheses:

| | | |
|---|---|---|
| $eat := S/NP : eat'$ | $veggies := NP : veg'$ | |
| $eat := S/NP : eat'$ | $veggie := NP : veg'$ | $\text{-}s := NP\backslash NP : plu'$ |
| $eat := NP : eat'$ | $veggies := S\backslash NP : \lambda x.veg' x$ | |
| $eat := NP : veg'$ | $veggies := S\backslash NP : \lambda x.eat' x$ | |
| $eat := S/NP : eat'$ | $veggie := NP/NP : plu'$ | $\text{-}s := NP : veg'$ |

impossible hypotheses:

| | | |
|---|---|---|
| $*eat := NP : eat'$ | $veggies := S/NP : veg'$ | |
| $*eat := S\backslash NP : eat'$ | $veggies := NP : veg'$ | |
| $*eat := S\backslash NP : eat'$ | $veggie := NP : veg'$ | $\text{-}s := NP\backslash NP : plu'$ |

# No veggies.

Assume: chocolate around

## Experience 1 (Eat veggies)

eat $:= S/NP : eat'$
$\quad : veg'$
$\quad NP : eat'$
$\quad : veg'$

veggies $:= S\backslash NP : veg'$
$\quad : eat'$
$\quad : plu'\ veg'$
$\quad : plu'\ eat'$
$\quad NP : veg'$
$\quad : eat'$
$\quad : plu'\ veg'$
$\quad : plu'\ eat'$

veggie $:= NP : veg'$
$\quad NP/NP : plu'$
$\quad : veg'$

-s $:= NP\backslash NP : plu'$
$\quad NP : veg'$

## Experience 2 (No veggies; with chocolate)

no $:= S/NP : no'$
$\quad : veg'$
$\quad : choc'$

veggies $:= S\backslash NP : no'$
$\quad : veg'$
$\quad : choc'$
$\quad : eat'$
$\quad : plu'\ veg'$
$\quad : plu'\ choc'$
$\quad : plu'\ no'$
$\quad NP : veg'$
$\quad : eat'$
$\quad : no'$
$\quad : choc'$
$\quad : plu'\ veg'$
$\quad : plu'\ choc'$
$\quad : plu'\ no'$

veggie $:= NP : no'$
$\quad : veg'$
$\quad : choc'$
$\quad NP/NP : plu'$
$\quad : veg'$
$\quad : choc'$

-s $:= NP\backslash NP : plu'$
$\quad NP : veg'$
$\quad : choc'$

Even in this circumscribed world of two experiences only, the child is exponentially less likely to believe that veggies could mean negation, eating, plural or chocolate, rather than veggies.

# Veggies gone.

$$
\begin{array}{rll}
\text{veggies} := & S/NP & : \mathit{veg}' \\
 & & : \mathit{gone}' \\
 & & : \mathit{eat}' \\
 & & : \mathit{no}' \\
 & & : \mathit{plu}'\,\mathit{veg}' \\
 & NP & : \mathit{veg}' \\
 & & : \mathit{gone}' \\
 & & : \mathit{eat}' \\
 & & : \mathit{no}' \\
 & & : \mathit{plu}'\,\mathit{gone}'
\end{array}
$$

$$
\begin{array}{rll}
\text{gone} := & S\backslash NP & : \mathit{veg}' \\
 & & : \mathit{gone}' \\
 & NP & : \mathit{veg}' \\
 & & : \mathit{gone}'
\end{array}
$$

$$
\begin{array}{rll}
\text{veggie} := & NP & : \mathit{veg}' \\
 & & : \mathit{no}' \\
 & NP/NP & : \mathit{veg}' \\
 & & : \mathit{plu}'
\end{array}
$$

$$
\begin{array}{rll}
\text{-s} := & NP\backslash NP & : \mathit{plu}' \\
 & NP & : \mathit{veg}' \\
 & S/NP & : \mathit{gone}' \\
 & & : \mathit{veg}' \\
 & & : \mathit{plu}'
\end{array}
$$

$$
\{\text{veggies, veggie}\} := \{ \begin{array}{lll}
S\backslash NP{:}veg' @ \frac{2}{55}, & S\backslash NP{:}eat' @ \frac{2}{55}, & S\backslash NP{:}no' @ \frac{1}{55}, \\
S\backslash NP{:}choc' @ \frac{1}{55}, & S\backslash NP{:}plu'\,veg' @ \frac{2}{55}, & S\backslash NP{:}plu'\,eat' @ \frac{1}{55}, \\
S\backslash NP{:}plu'\,no' @ \frac{1}{55}, & S\backslash NP{:}plu'\,choc' @ \frac{1}{55}, & \\
S/NP{:}veg' @ \frac{2}{55}, & S/NP{:}gone' @ \frac{2}{55}, & S/NP{:}eat' @ \frac{1}{55}, \\
S/NP{:}no' @ \frac{1}{55}, & S/NP{:}plu' @ \frac{1}{55}, & S/NP{:}plu'\,veg' @ \frac{1}{55}, \\
NP{:}veg' @ \frac{9}{55}, & NP{:}eat' @ \frac{3}{55}, & NP{:}plu'\,veg' @ \frac{2}{55}, \\
NP{:}plu'\,eat' @ \frac{1}{55}, & NP{:}plu'\,gone' @ \frac{1}{55} & NP{:}plu'\,choc' @ \frac{1}{55}, \\
NP{:}plu'\,no' @ \frac{1}{55}, & NP{:}no' @ \frac{4}{55}, & NP{:}choc' @ \frac{3}{55}, \\
NP{:}gone' @ \frac{1}{55} & & \\
NP\backslash NP{:}plu' @ \frac{3}{55}, & & \\
NP/NP{:}plu' @ \frac{3}{55}, & NP/NP{:}veg' @ \frac{3}{55}, & NP/NP{:}choc' @ \frac{1}{55}
\end{array} \}
$$

# Other experiences with approximate but probable meanings

- Planning
- Music
- Vision
- Art

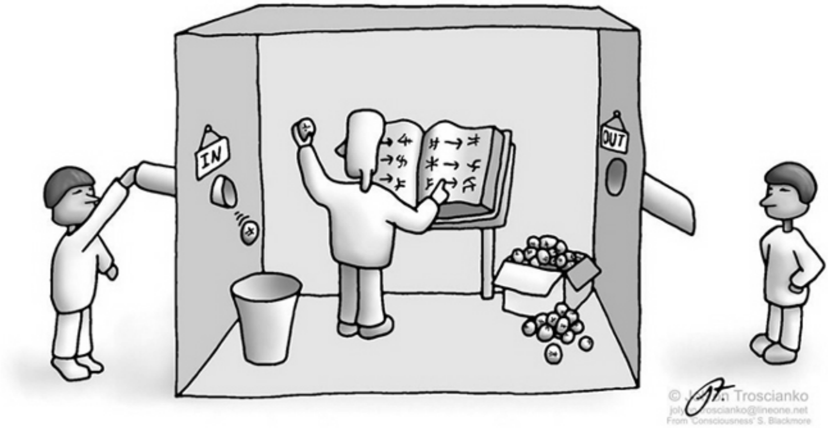
- All high-level cognitive processes are massively serial
- All low-level processes are massively parallel
- Need for symbols seems to be the key
  for the bottleneck (Deacon 1997, 2012)
- Unexpected contribution of grammars in all these domains
- All we need to engender meaning of this sort is a mechanism to execute the grammatical process

# Summary

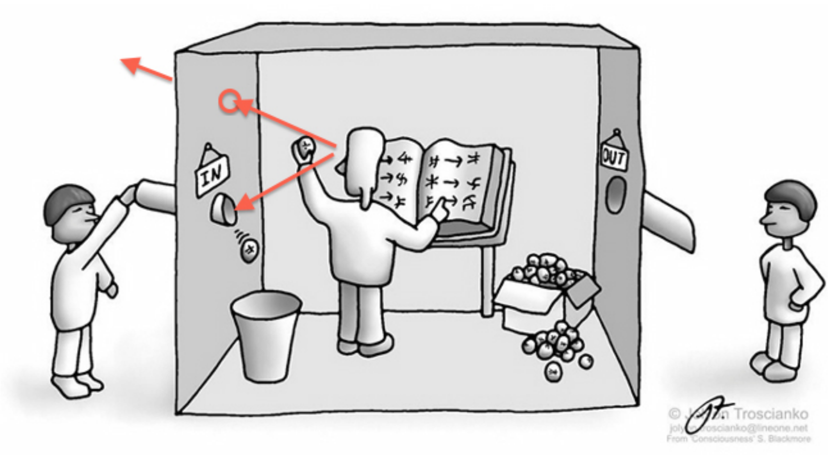
- Humans are doing computations too, when they learn grammar and words
- Searle is a pessimist, and Turing an optimist about artificial systems doing the same thing
- Cognitive science, esp. computational linguistics, shows how the process can be conceived computationally

  : for humans, and for other things with interpretable hardware
- That's their "right stuff"

# Helen Keller was not in this room



# She was in here




Meaning is not observer-relative in this room, but owner-caused.

# Sad but true

- The kind of meanings that can be expressed causes the same problems for the owners with the right hardware
  - ambiguity in perception and use
  - indeterminacy and likelihood
  - resource boundedness

# Concluding remarks

- If we worry about the complexity of a problem, computation as we know today can only give rise to PAC meanings*
    - Only they can be given a causal history of their construal with reasonable resources
    - Valiant (1984): "Inherent algorithmic complexity appears to set serious limits to the range of concepts that can be learned."
    - Transfinite representations can be talked about (e.g. $\pi$)
    - but cannot be pinned down (not even the PAC-way)

*Probably Approximately Correct. Valiant 1984: "we regard learning as the phenomenon of knowledge acquisition in the absence of explicit programming." The selected hypothesis has high probability for low generalization error.

- Can we look into the brain and see the meaning?
  - Probably not
  - (can we see a running process in a machine?)
  - But we might be able to construct a personal history for a meaning associated with a form
  - These meanings would not be observer-relative
- Meaning is a process in relation to a representation

# Thanks to:

- You
- GRAMPLUS project http://groups.inf.ed.ac.uk/gramplus/ (Univ. of Edinburgh, PI: Mark Steedman)
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- Umut Özge
- Samet Bağçe
- Albert Ali Salah
- İlhan İnan
- My Advisor, Nicholas V. Findler (1930-2013), who got me into this back in 1987
- Leonard "Aryeh" Faltz, my other mentor, who got me out

# Some references


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