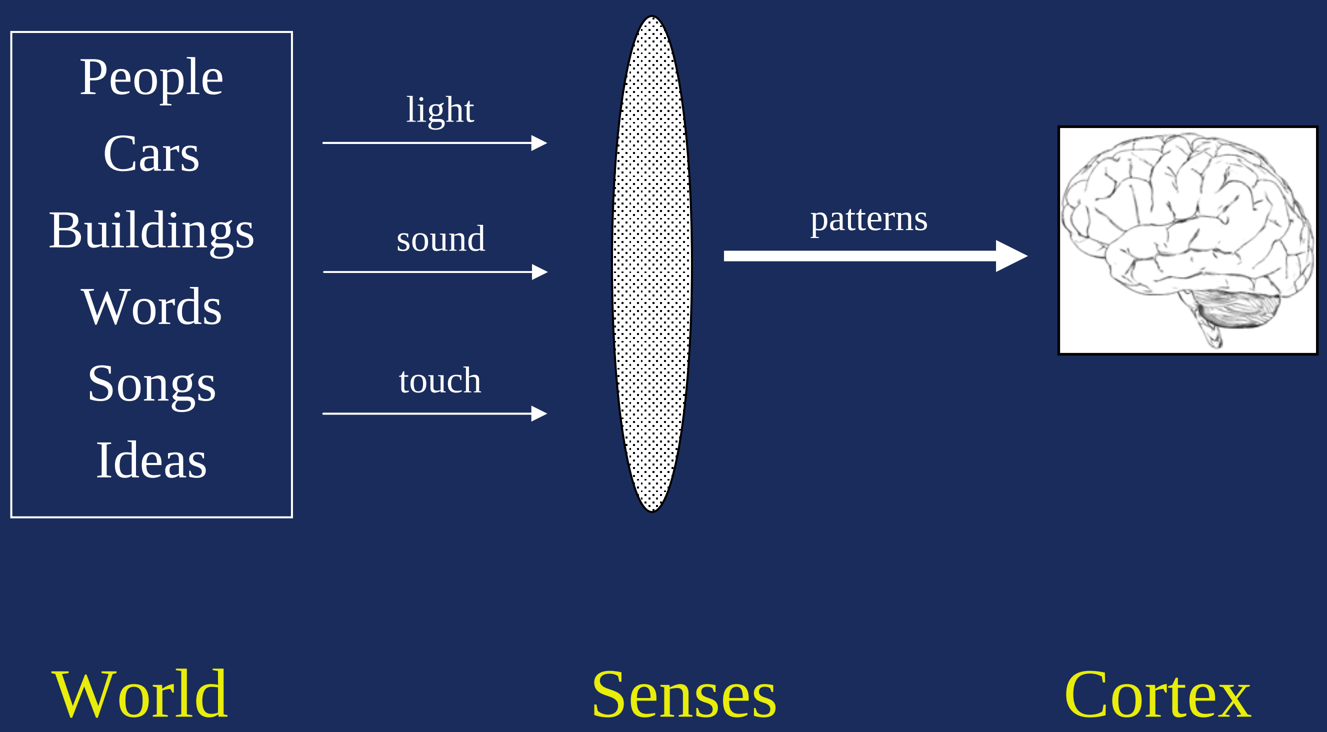
Computing Beyond Turing

How neocortical theory can lead to machine intelligence

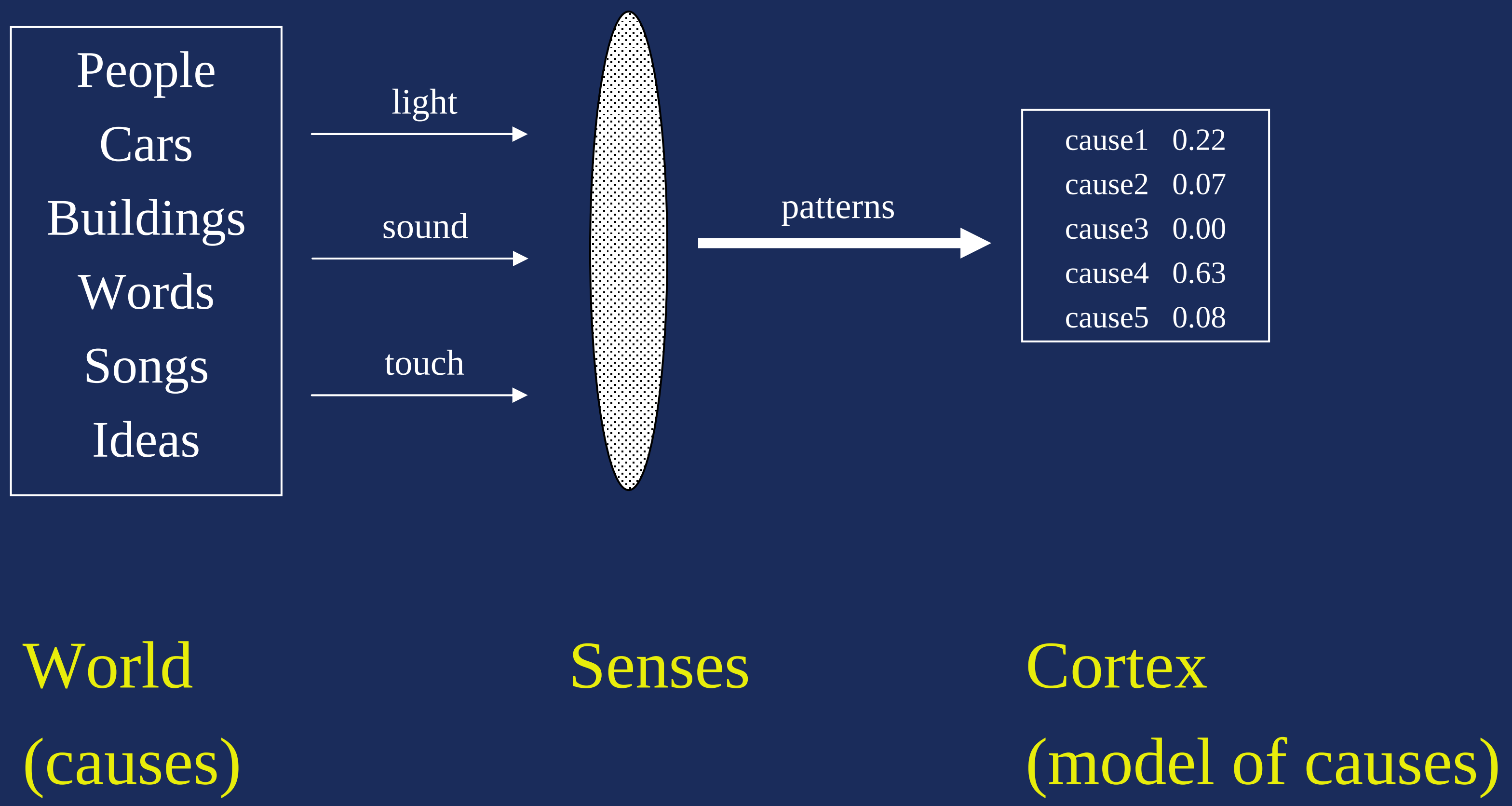
Stanford Computer Forum
April 15, 2009
Jeff Hawkins
Numenta

What Does Cortex Do?

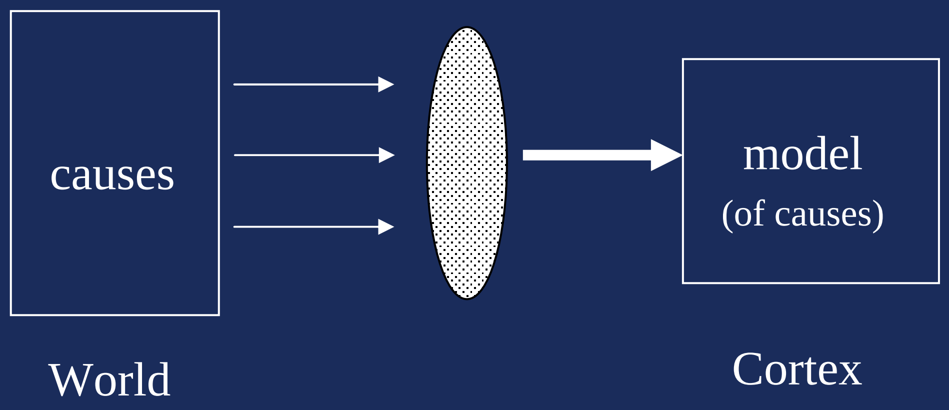


What Does Cortex Do?

- It builds a model of the world -



What Cortex Does

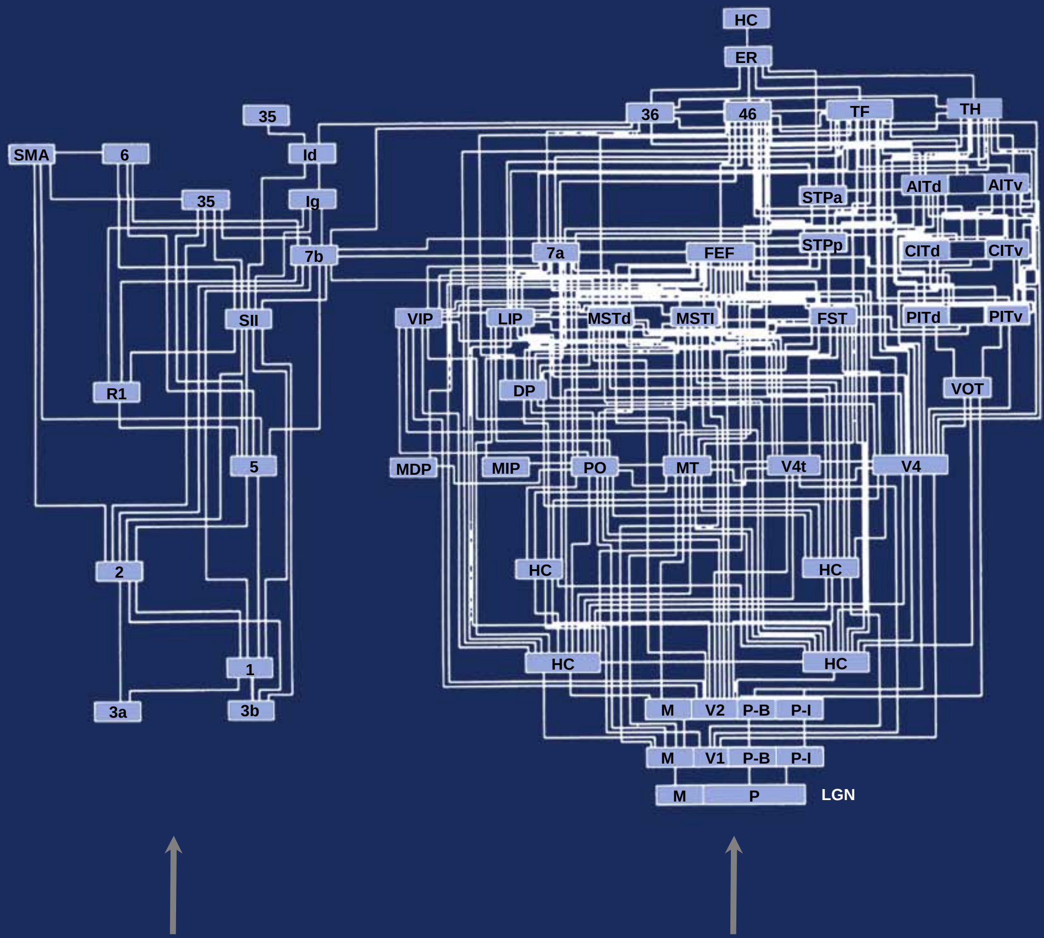


1 Discovers causes in the world

2 Infers causes of novel input

3 Predicts future

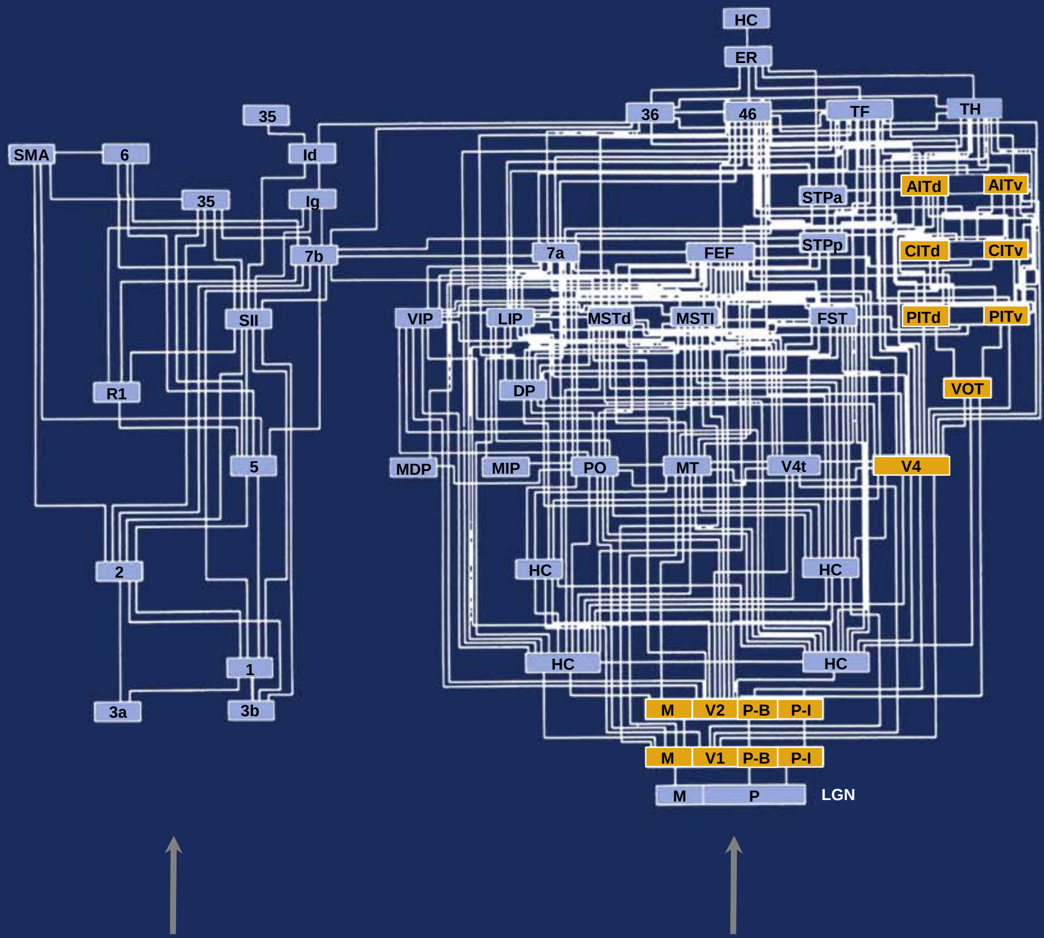
4 Creates motor behavior



Sensory data
(skin)

Sensory data
(retina)

- Knowledge is distributed hierarchically
- Self training through changing sensory patterns
- Each region is similar



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Sensory data (retina)

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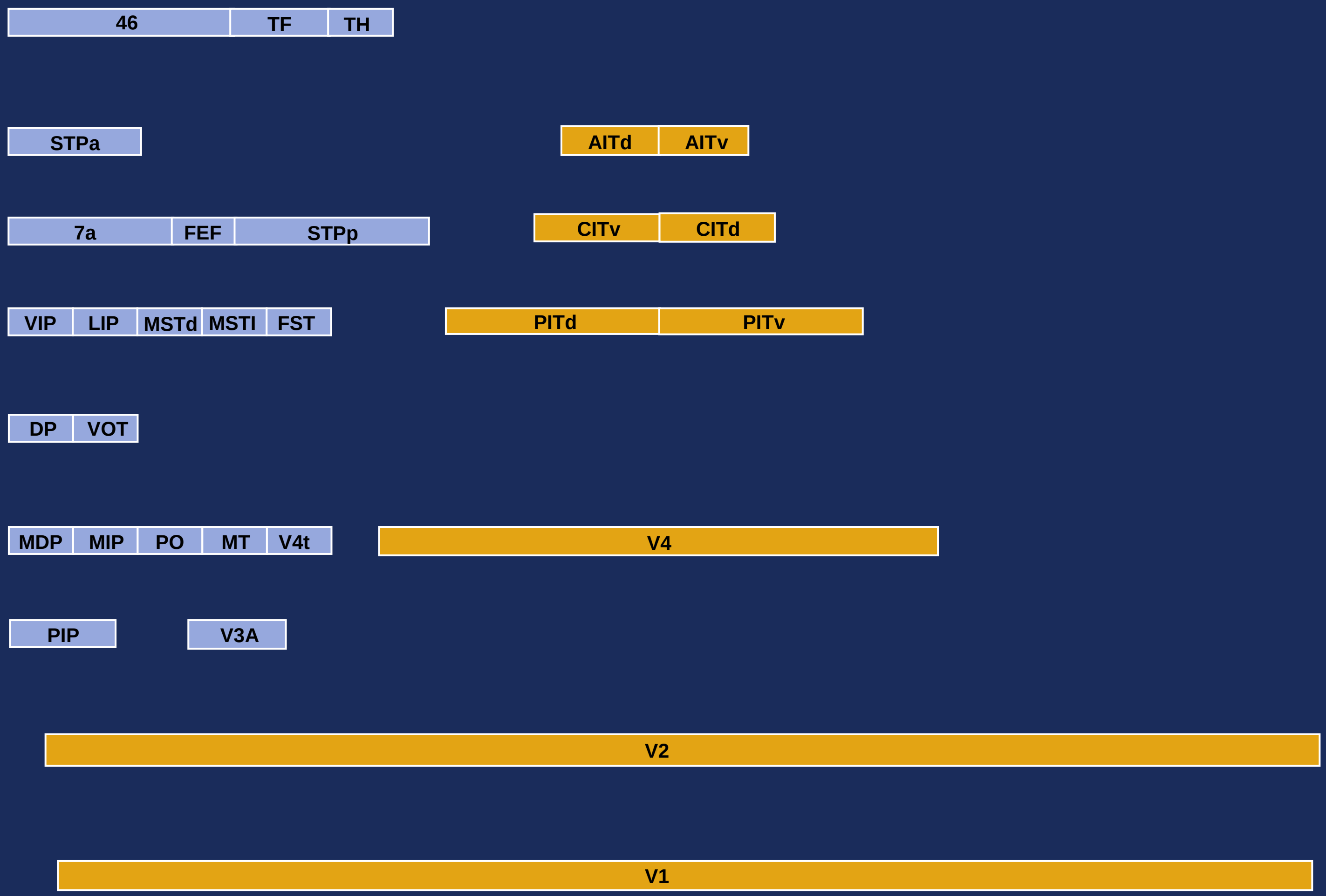
46
TF
TH
STPa
AITd
AITv
7a
FEF
STPp
CITv
CITd
VIP
LIP
MSTd
MSTl
FST
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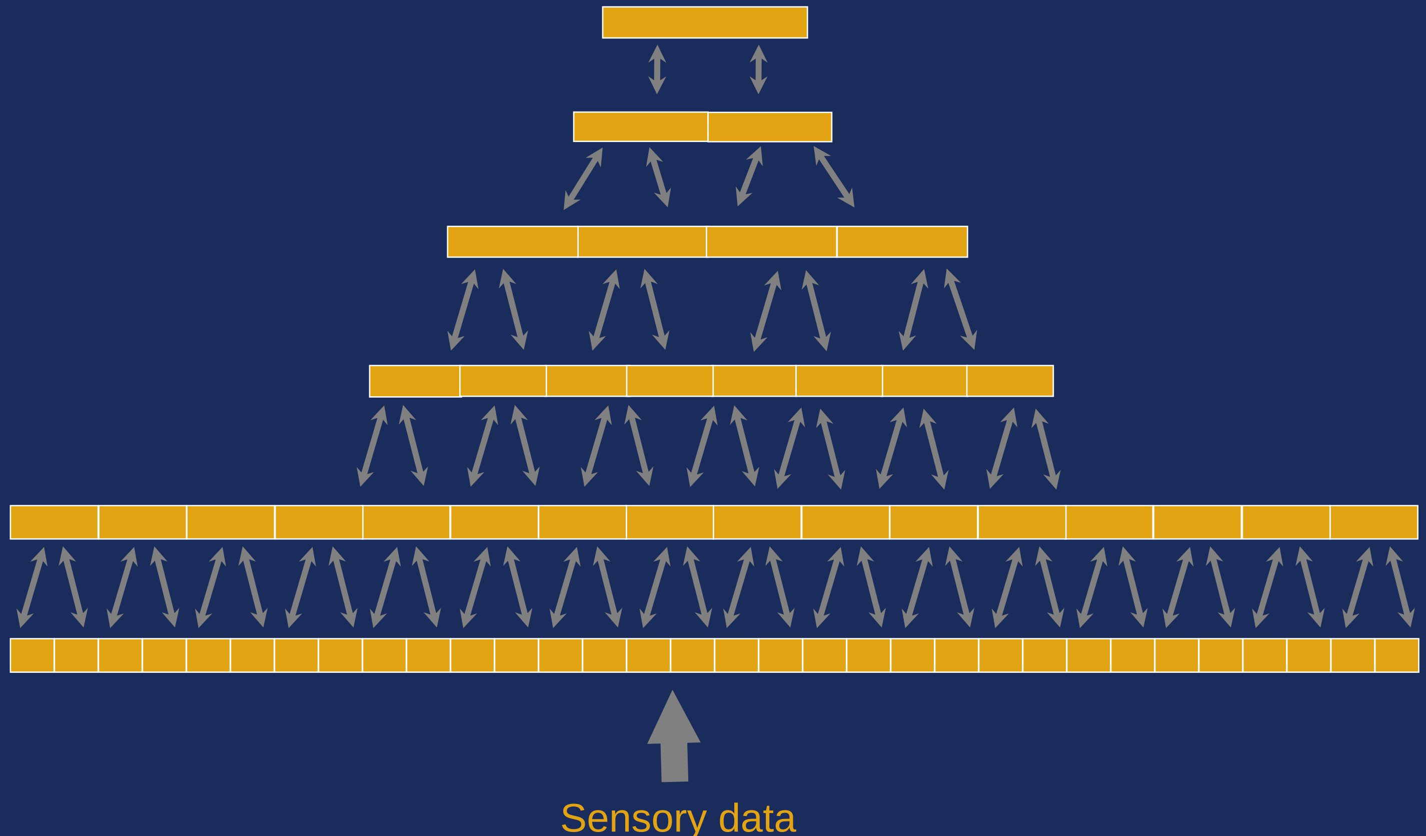
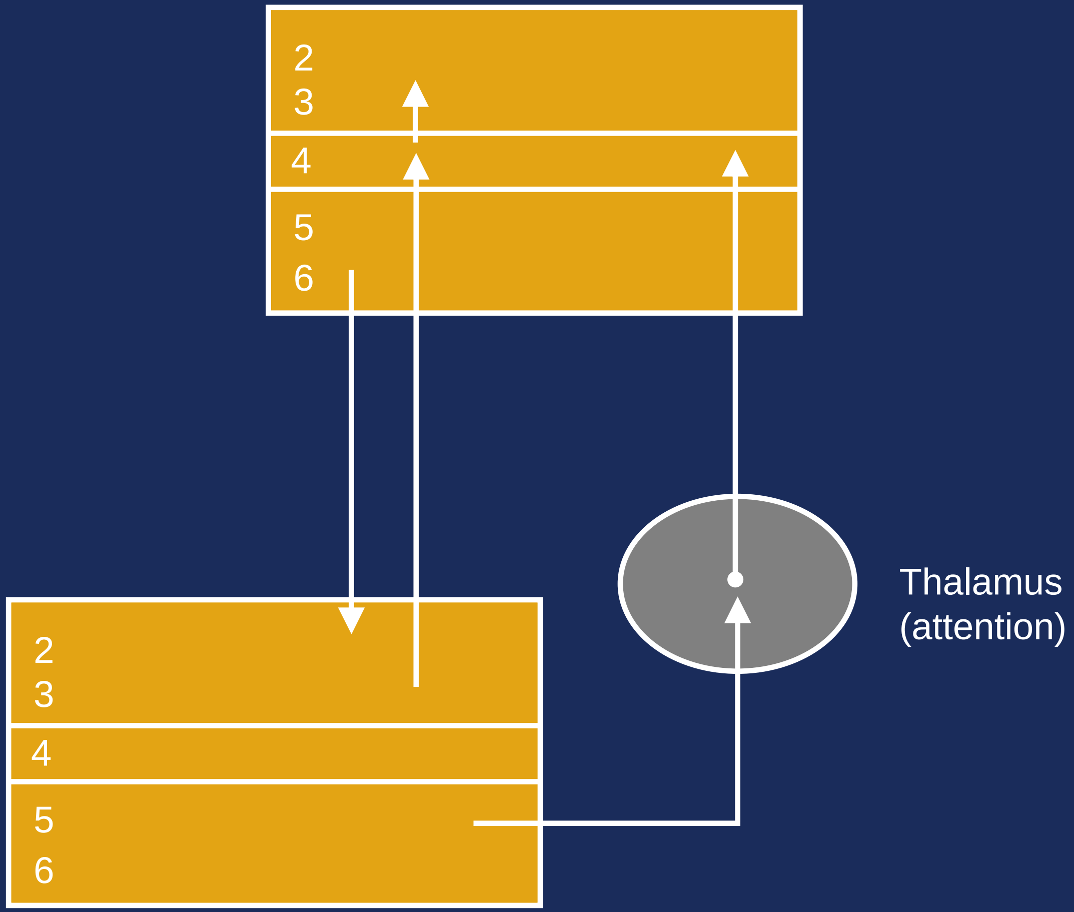
V3A
V2
V1


Sensory data


2
3
4
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6
2
3
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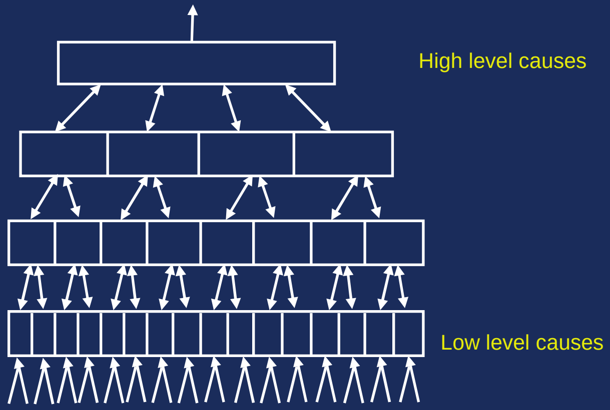
6
Thalamus
(attention)

Hierarchical Temporal Memory



Each node

- Learns common spatial patterns
- Learns common sequences

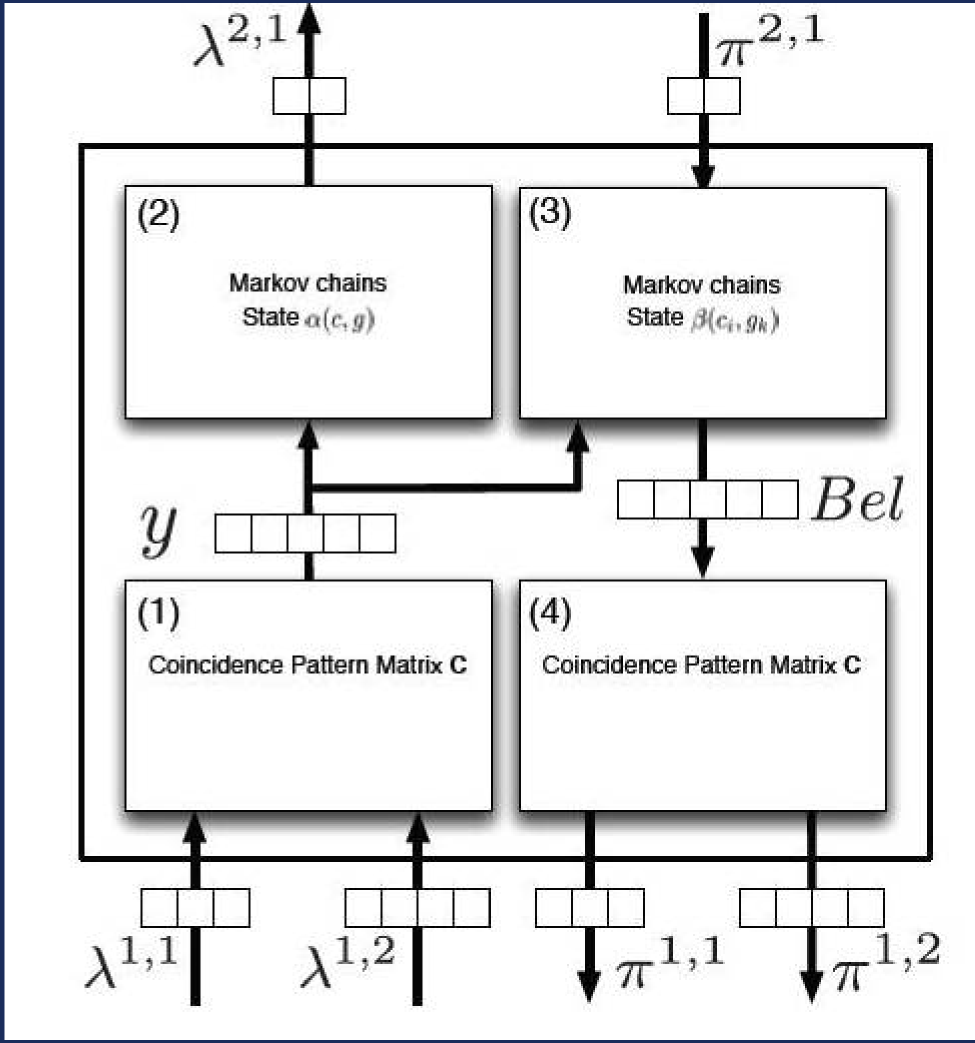
Sequence names passed up

Predicted spatial patterns passed down

Creates hierarchical model of causes

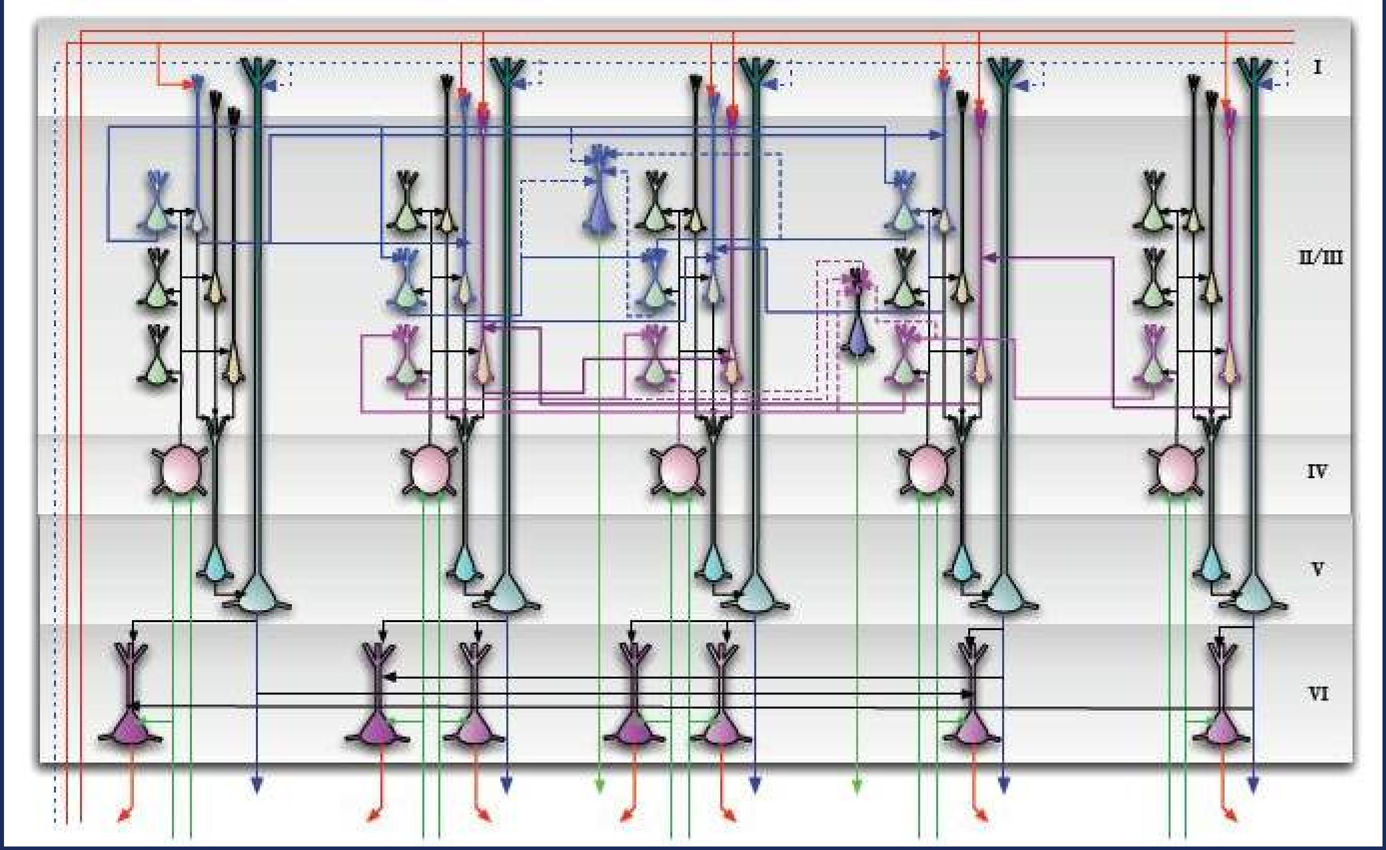
Bayesian methods resolve ambiguity

Belief Propagation In an HTM Node

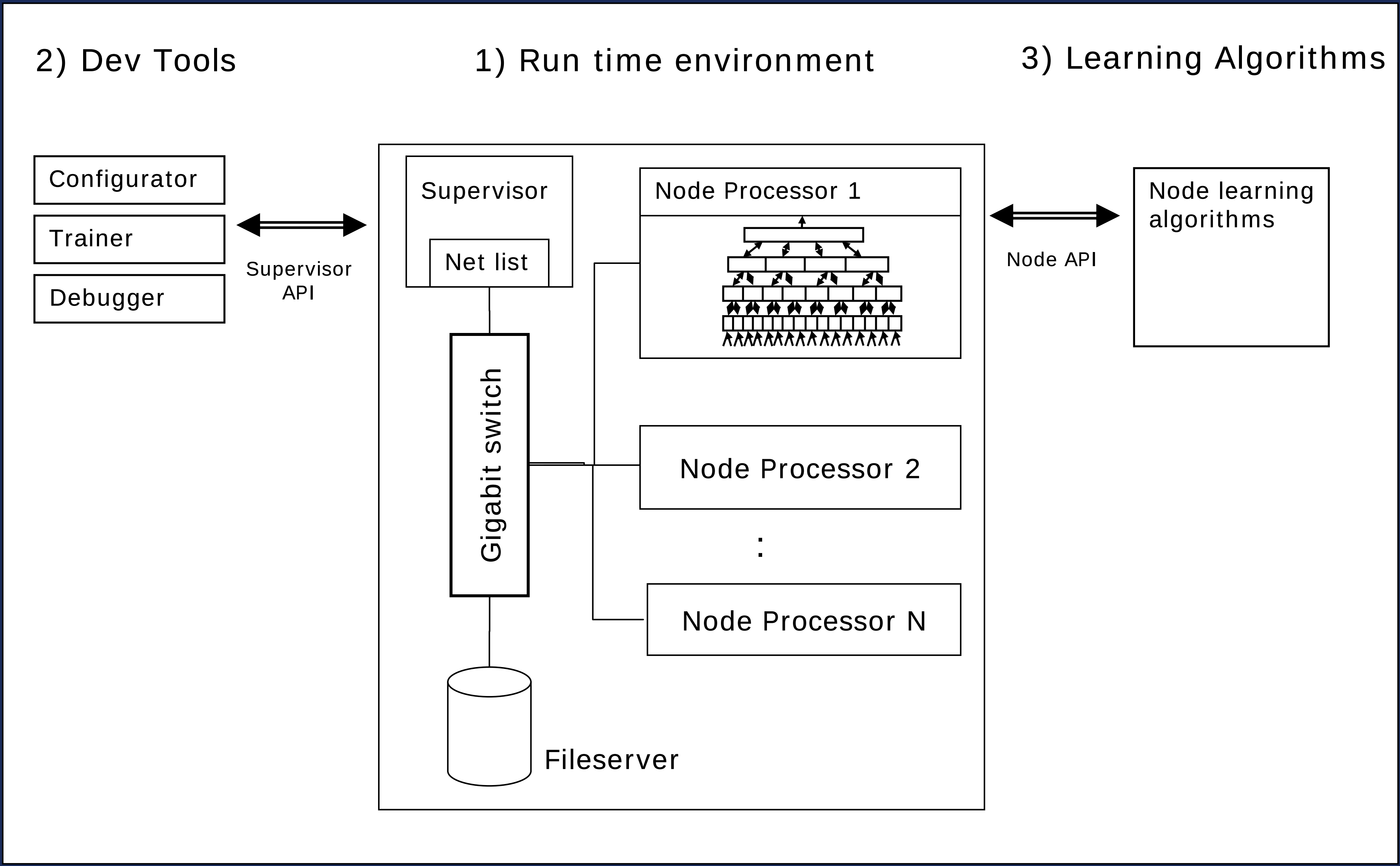


Belief Propagation Equations In an HTM Node

1) Calculate likelihood over coincidence-patterns.	$$y_t(i) = P(^{-}e_t \mid c_i(t)) \propto \prod_{j=1}^{M} \lambda_t^{m_j}(r_i^{m_j}) \quad (4.1)$$ where coincidence-pattern c_i is the co-occurrence of $r_i^{m_1}$'th Markov chain from child 1, $r_i^{m_2}$'th Markov chain from child 2, $\cdots$, and $r_i^{m_M}$'th Markov chain from child M.
2) Feed-forward probability over Markov chains (temporal groups) using dynamic programming	$$\lambda_t^k(g_r) = P(^{-}e_0^t \mid g_r(t)) \propto \sum_{c_i(t) \in C^k} \alpha_t(c_i, g_r) \quad (4.2)$$ $$\alpha_t(c_i, g_r) = P(^{-}e_t \mid c_i(t)) \sum_{c_j(t-1) \in C^k} P(c_i(t) \mid c_j(t-1), g_r)\alpha_{t-1}(c_j, g_r) \quad (4.3)$$ $$\alpha_0(c_i, g_r) = P(^{-}e_0 \mid c_i(t=0))P(c_i(t=0) \mid g_r) \quad (4.4)$$
3) Calculate the belief distribution over coincidence patterns	$$Bel_t(c_i) \propto \sum_{g_r \in G^k} P(g_r \mid ^{+}e_0)\beta_t(c_i, g_r) \quad (4.5)$$ $$\beta_t(c_i, g_r) = P(^{-}e_t \mid c_i(t)) \sum_{c_j(t-1) \in C^k} P(c_i(t) \mid c_j(t-1), g_r)\beta_{t-1}(c_j, g_r) \quad (4.6)$$ $$\beta_0(c_i, g_r) = P(^{-}e_0 \mid c_i(t=0))P(c_i(t=0) \mid g_r, ^{+}e_0) \quad (4.7)$$
4) Calculate the messages to be sent to child nodes.	$$\pi^{child}(g_m) \propto \sum_{i \forall i} I(c_i)Bel(c_i) \quad (4.8)$$ where $$I(c_i) = \begin{cases} 1, & \text{if } g_m^{child} \text{ is a component of } c_i \\ 0, & \text{otherwise} \end{cases} \quad (4.9)$$


I
II/III
IV
V
VI

NuPIC, Numenta Platform for Intelligent Computing

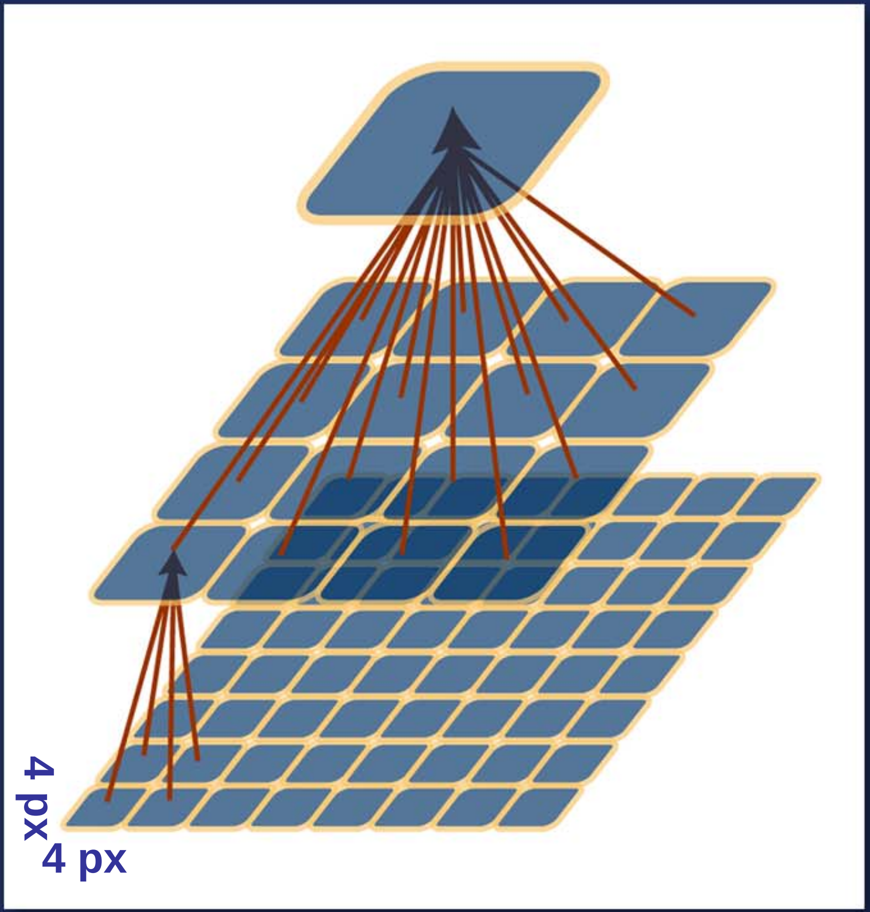








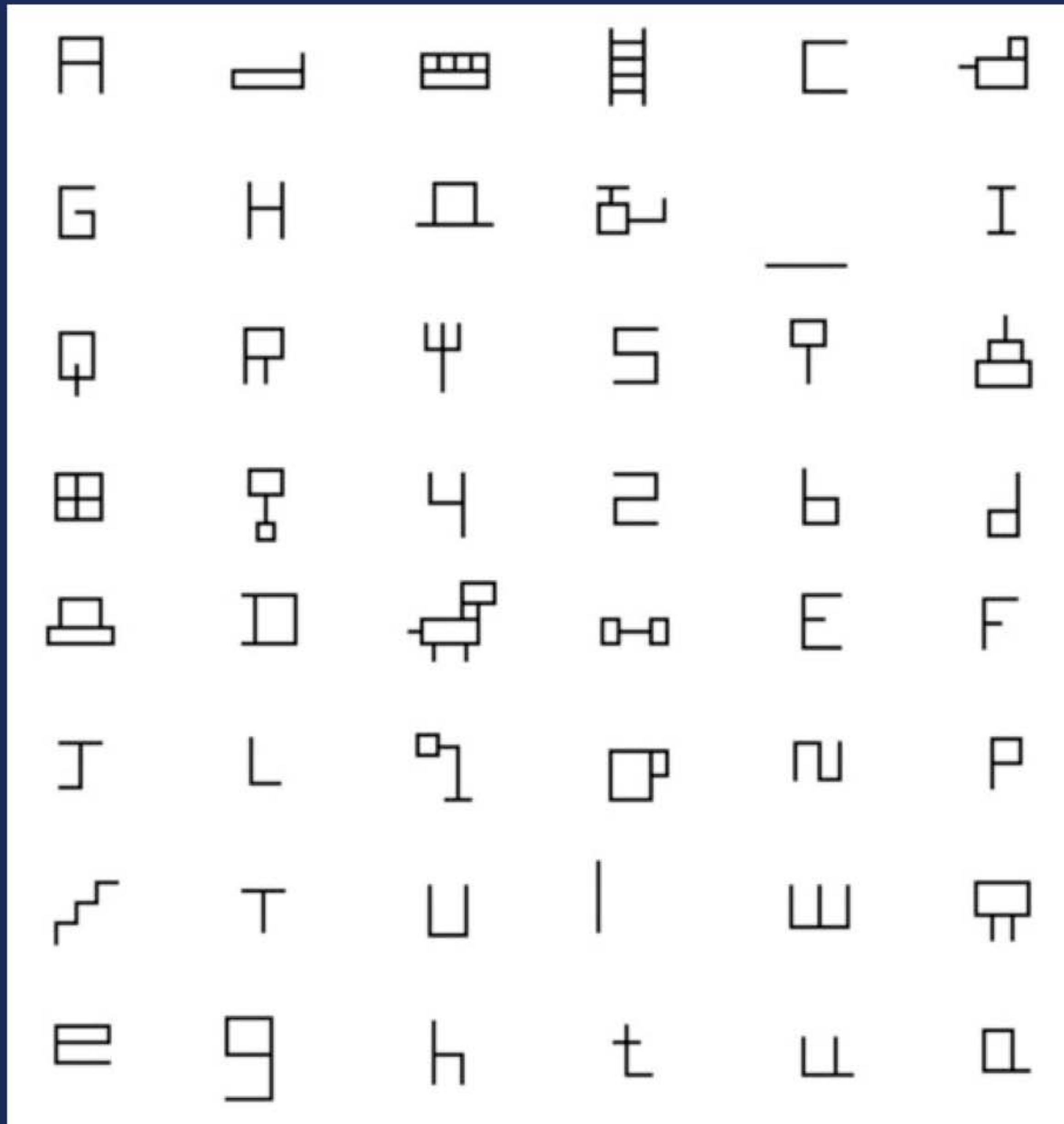

Pictures: Simple Vision System (32 x 32 Pixels)

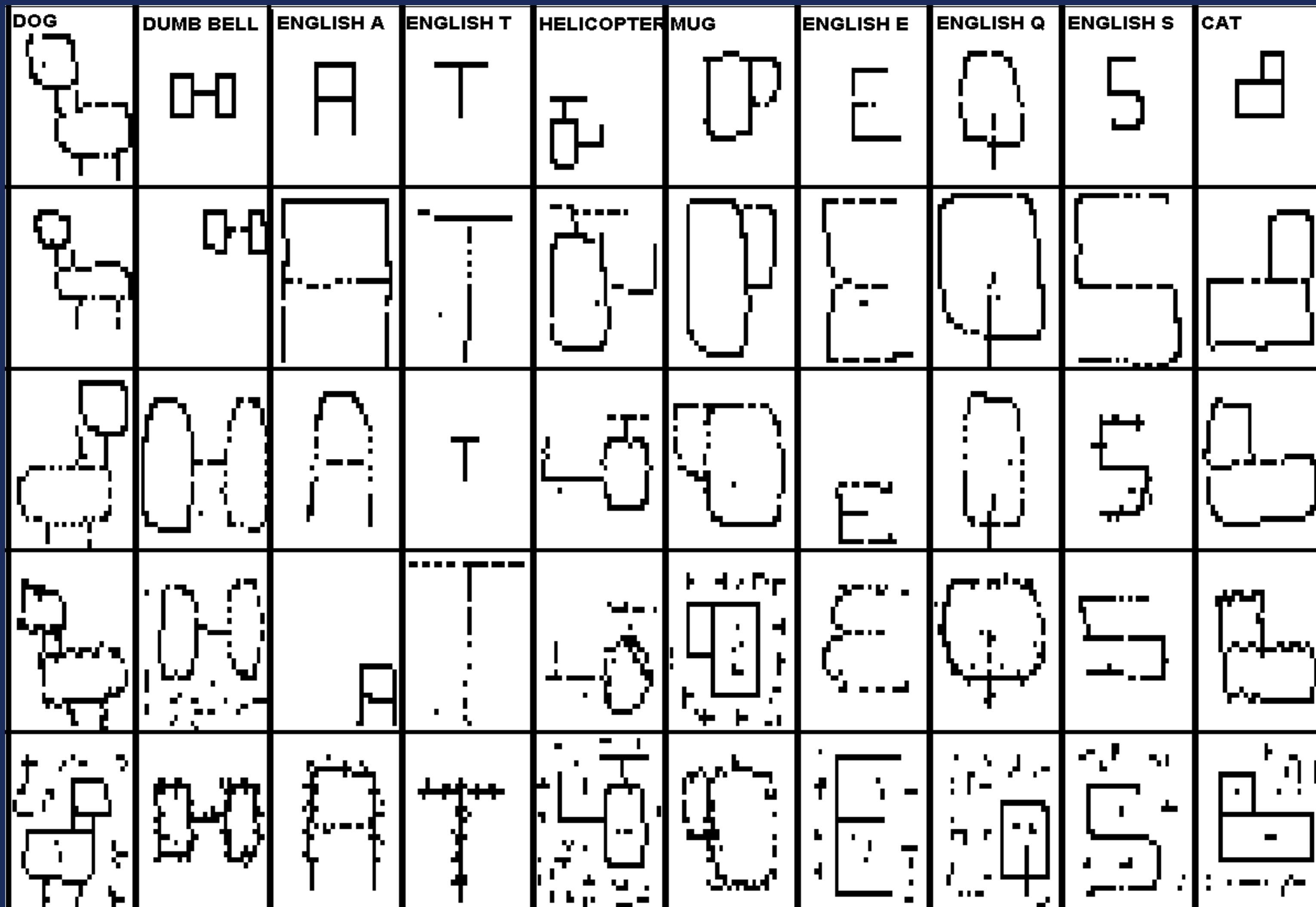


Level 3

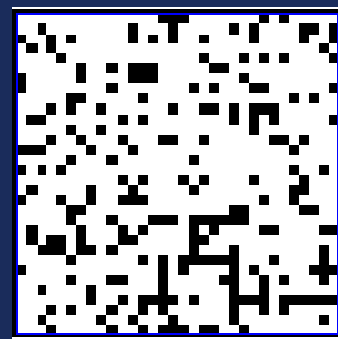
Level 2

Level 1



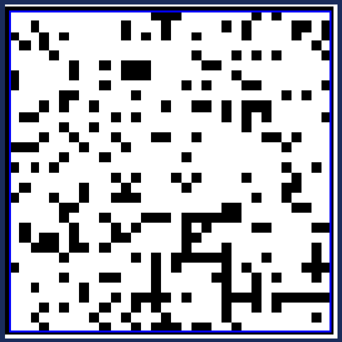

DOG
DUMB BELL
ENGLISH A
ENGLISH T
HELICOPTER
MUG
ENGLISH E
ENGLISH Q
ENGLISH S
CAT

Time Based Inference



Time Based Inference

Static inference
(with noise)



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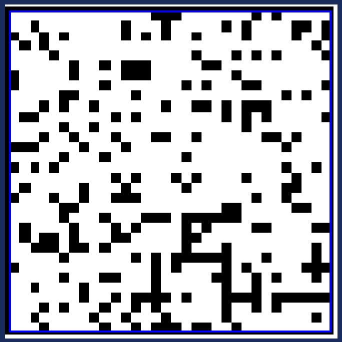
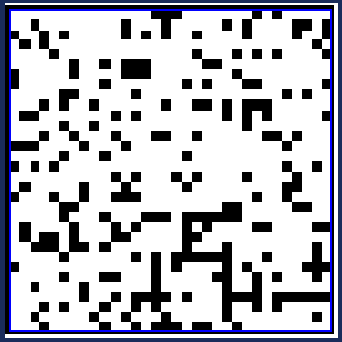
Time Based Inference

Static inference
(with noise)





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Time Based Inference

Static inference
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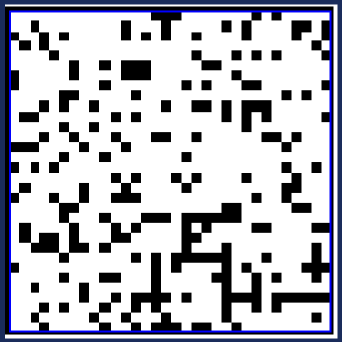

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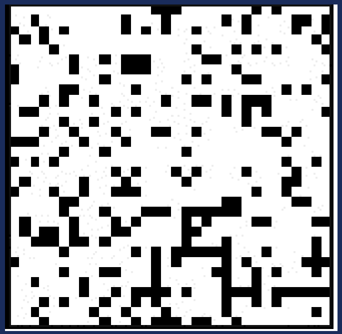

Time Based Inference

Static inference
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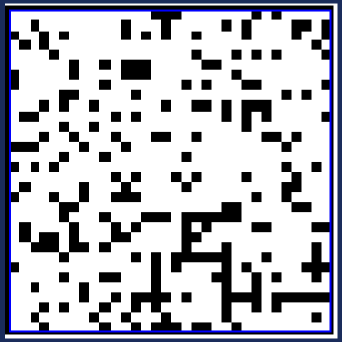

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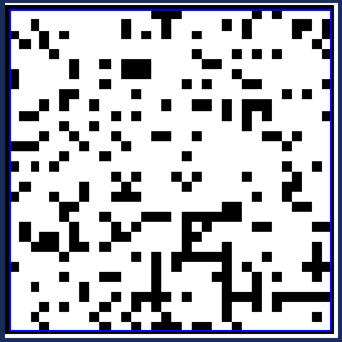
Time based inference
(with noise)



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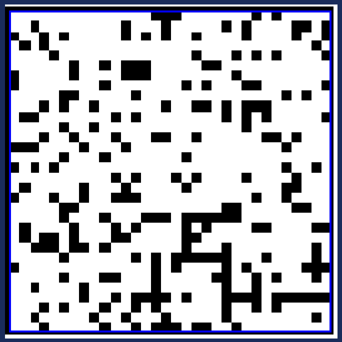
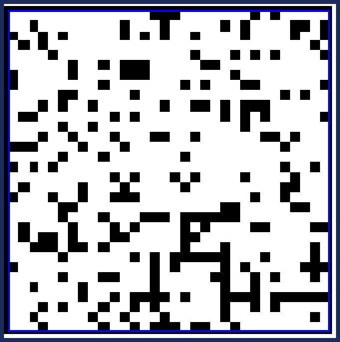
Time Based Inference

Static inference
(with noise)



19%

Time based inference
(with noise)



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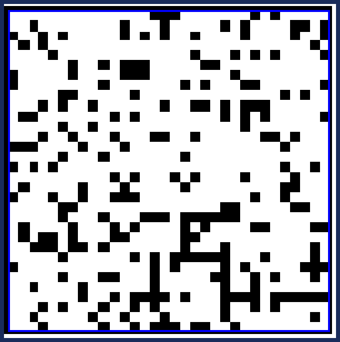
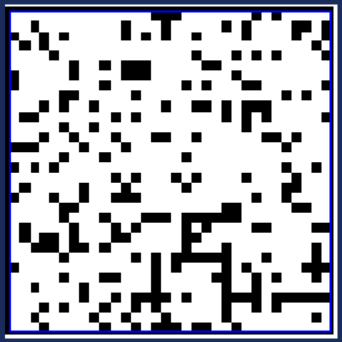


Time Based Inference

Static inference
(static noise)



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Time based inference
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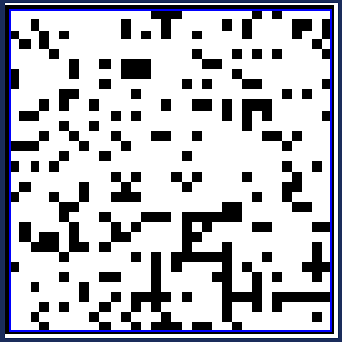

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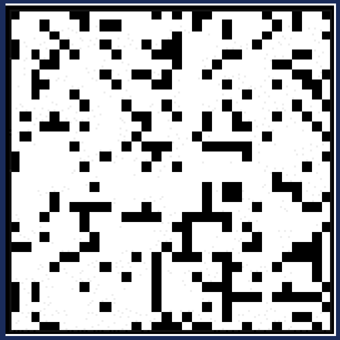

Time Based Inference

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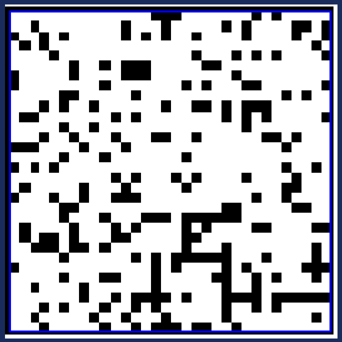

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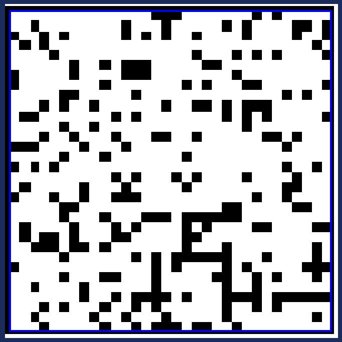

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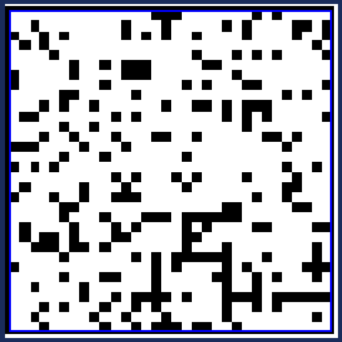
Time based inference
(with dynamic noise)



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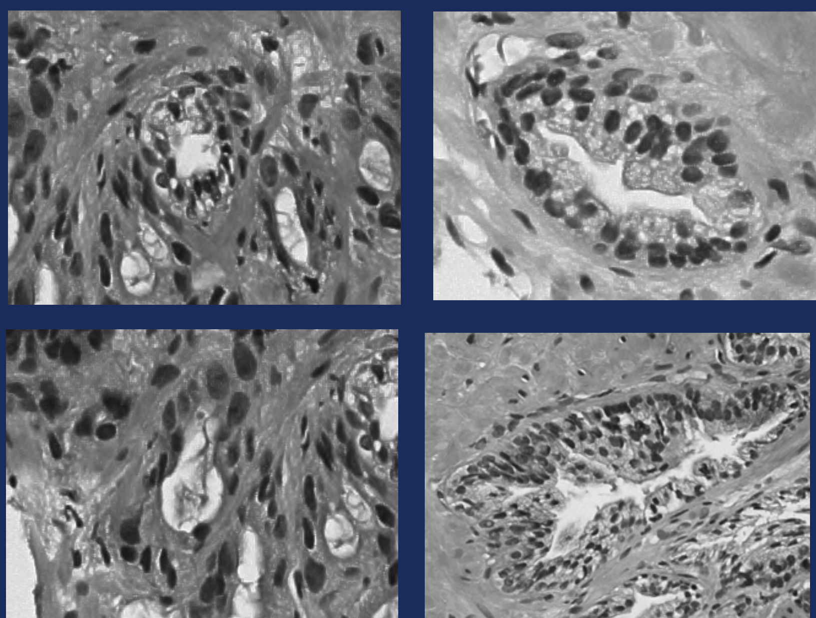
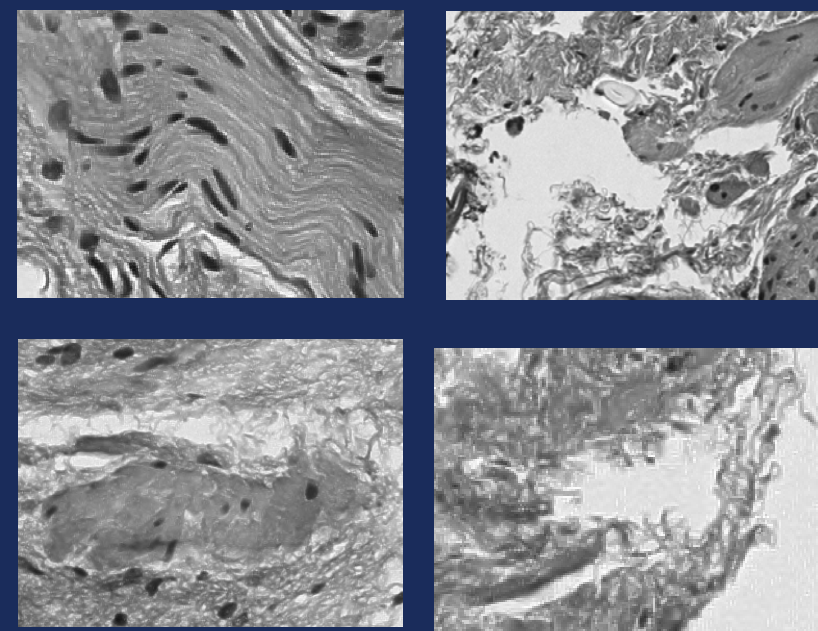
HTM Vision In Digital Pathology

- discriminate glands from other structures -



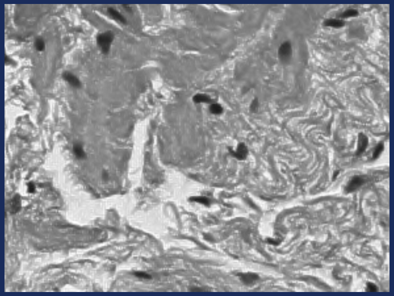
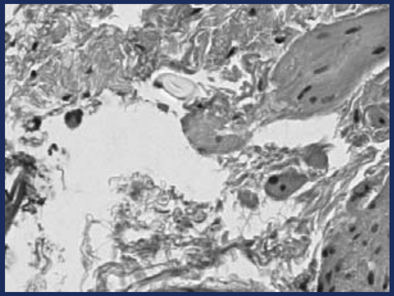
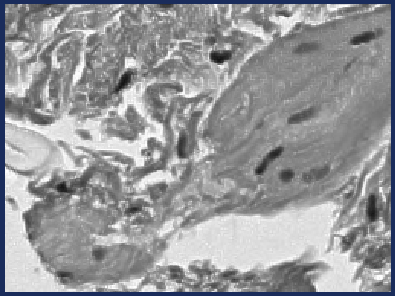
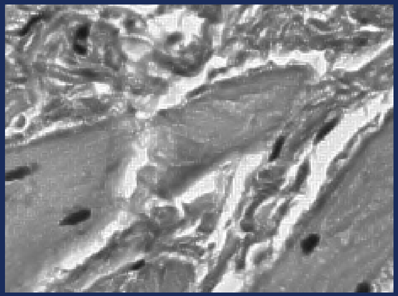
Glands



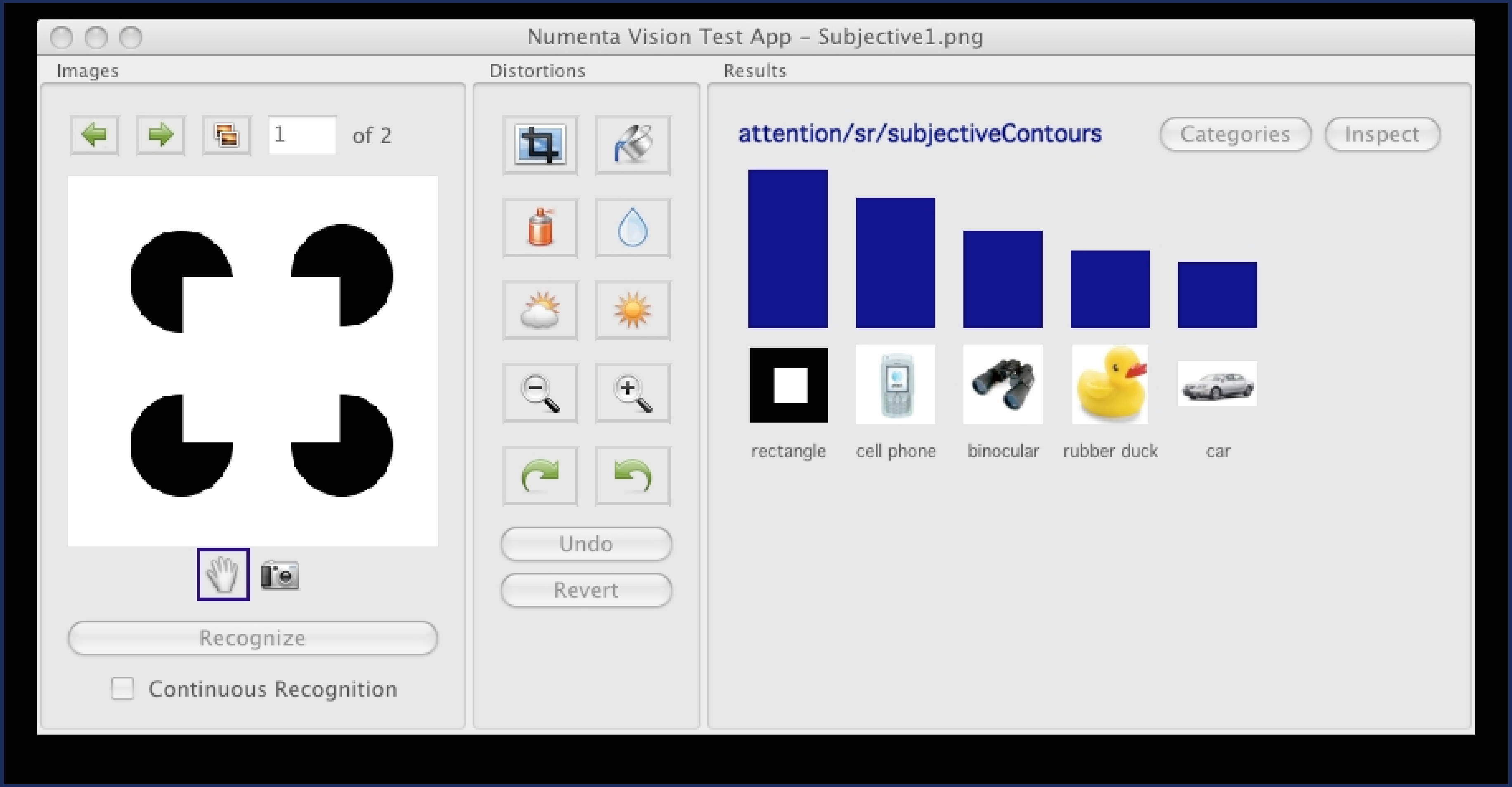
Not glands

Promising Early Results

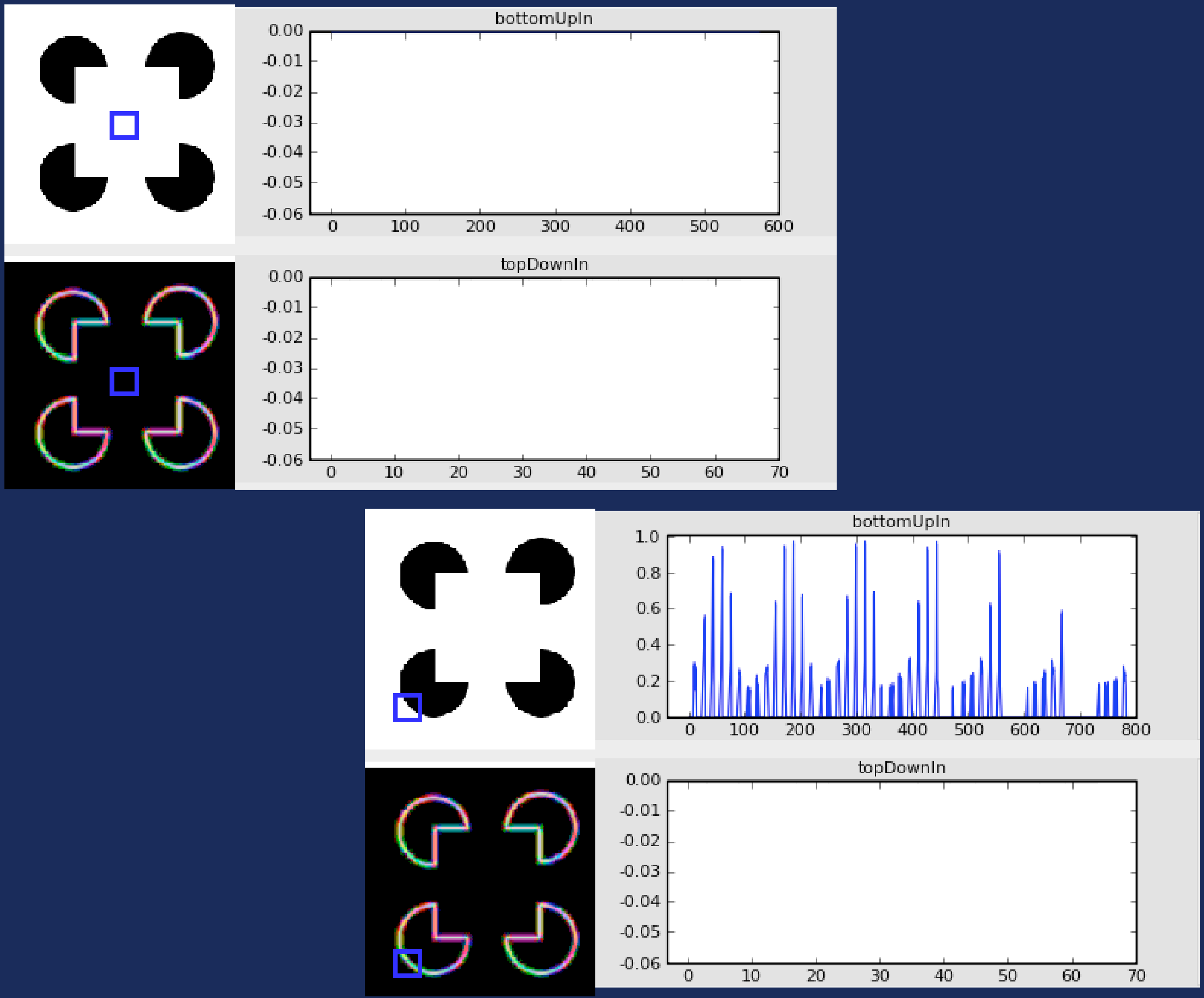
- We trained a network to recognize glands
  - Training set: 195 images of glands and non-glands
  - Test set: 80 novel images
- Result: test set accuracy was 95%
- The four errors were “reasonable”

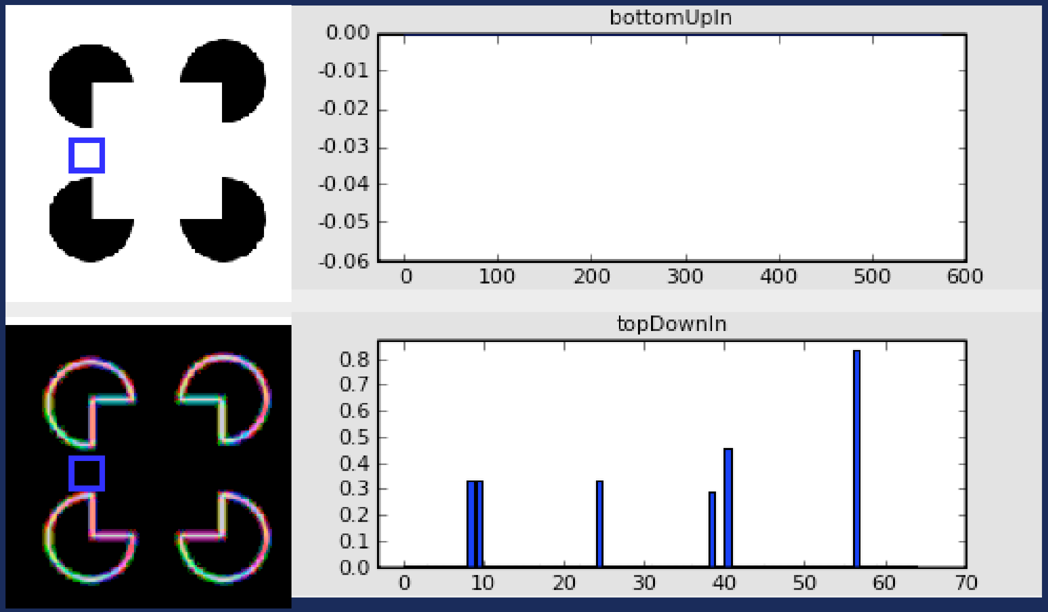
Illusory Contour



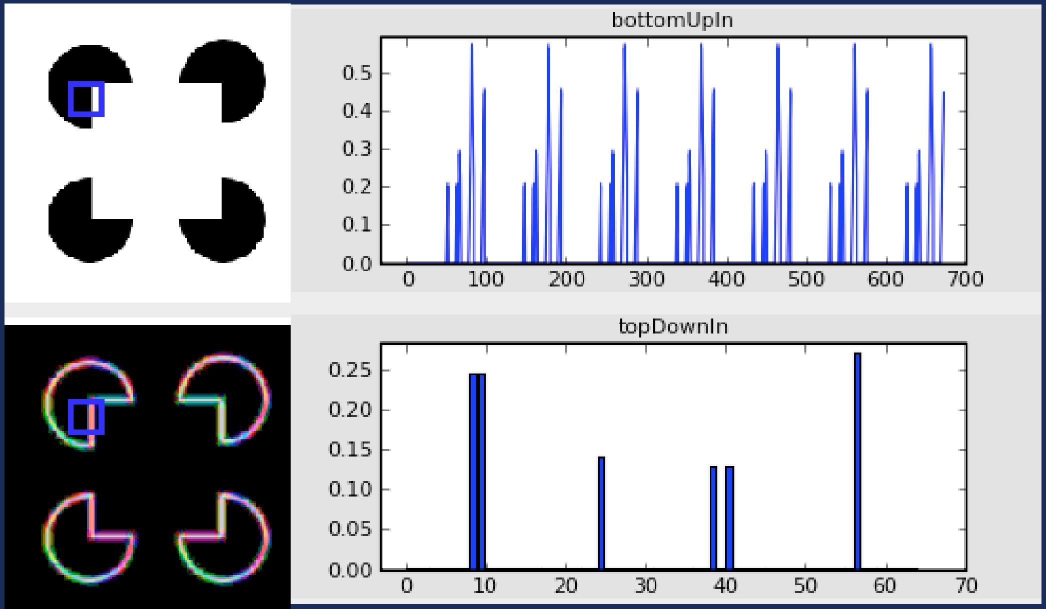
Illusory Contour



Illusory Contour



Perceived line with no bottom up support



HTM Application Areas

- Medical: Digital pathology
- Voice: Speaker/gender id
- Security: Video behavior recognition
- Auto: Lane change prediction

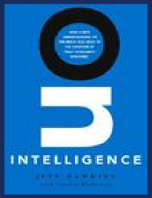
- Banking: Fraud detection
- Web: Analytics
- Pharma: Drug discovery
- Networks: Attacks and Failures
- Gaming: Motion capture inference
  Visual object editor
- Semantic analysis of text

Technical Challenges

- Algorithms
  - Sequence Memory algorithms
  - Attention mechanisms
  - Feedback
  - Sensory pre-processing

- Performance
- Silicon vs. software

To Learn More



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- Download NuPIC
- Attend HTM workshop June 25, San Jose, CA
- Internships or employment at Numenta

- jhawkins@numenta.com