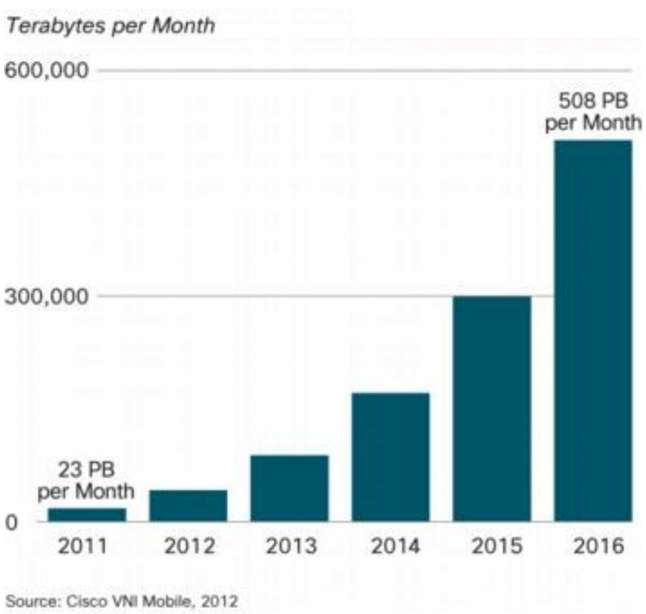
kno.e.sis

COLLECTING THE DOTS | CONNECTING THE DOTS

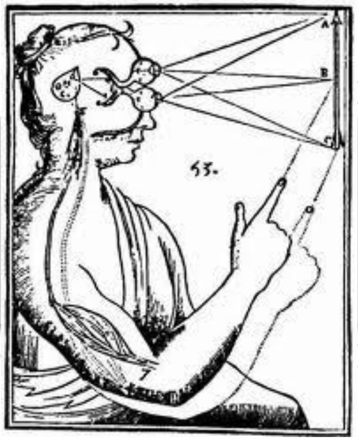
The Patient of the Future

MIT Technology Review, 2012

What if we could automate this *sense making* ability?



… and do it *efficiently* and at *scale*



01 001010110001101101101011000110100111001010110001101011000110100111

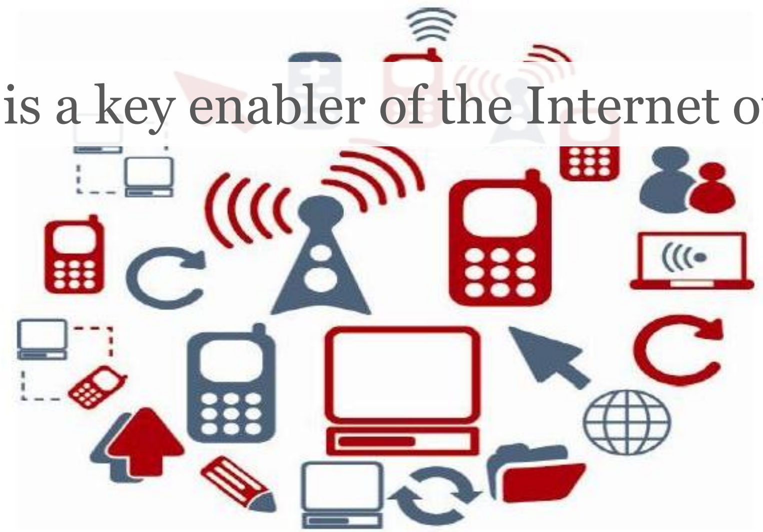
An Efficient Bit Vector Approach to Semantics-based Machine Perception in Resource-constrained Devices

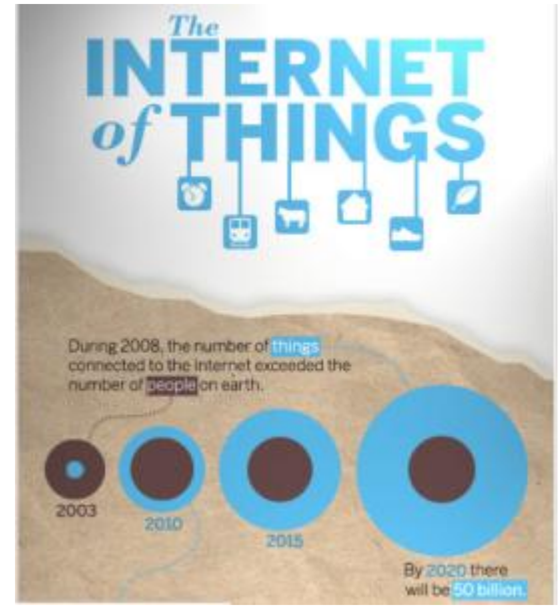
01 001010110001101101101011000110100111001010110001101011000110100111

Cory Henson, Krishnaprasad Thirunarayan, Amit Sheth

Kno.e.sis – Ohio Center of Excellence in Knowledge-enabled Computing
Wright State University, Dayton, OH, USA

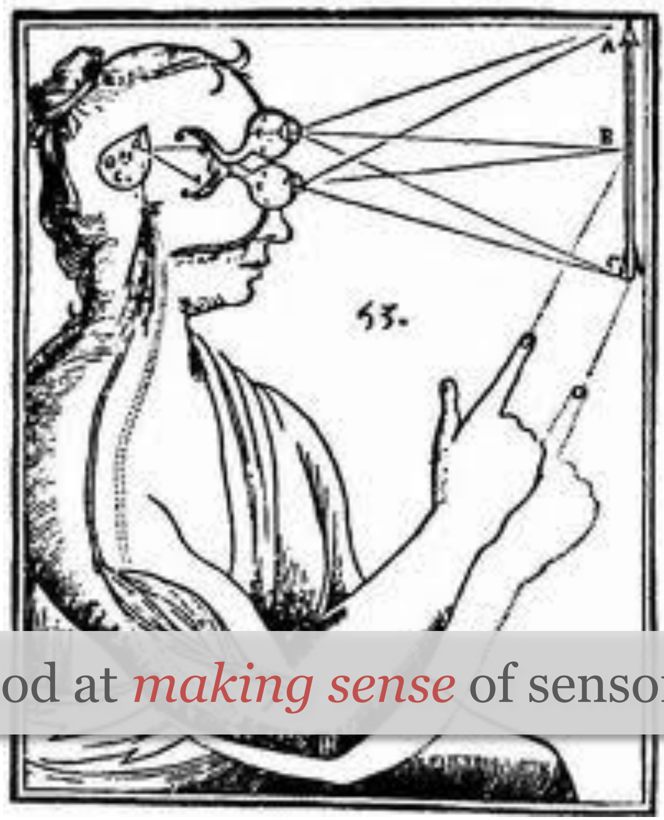
Sensing is a key enabler of the Internet of Things





50 Billion Things by 2020 (Cisco)

BUT, how do we *make sense* of the resulting avalanche of sensor data?



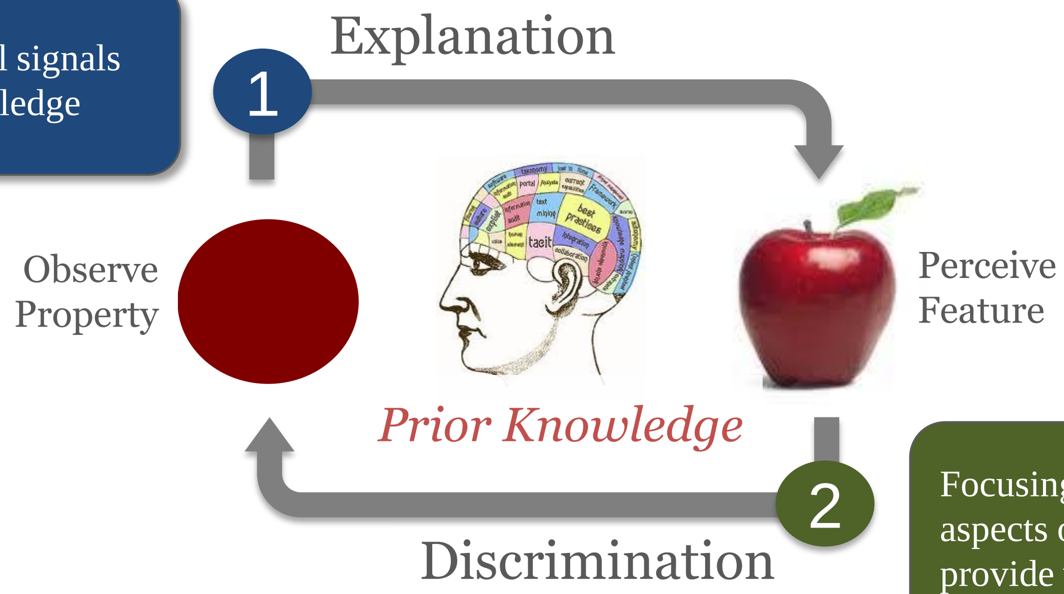
People are good at *making sense* of sensory input

What can we learn from cognitive models of perception?

- *The key ingredient is prior knowledge*

Perception Cycle*

Translating low-level signals into high-level knowledge



Focusing attention on those aspects of the environment that provide useful information

* based on Neisser's cognitive model of perception

To enable machine perception,

Semantic Web technology is used to integrate sensor data with prior knowledge on the Web

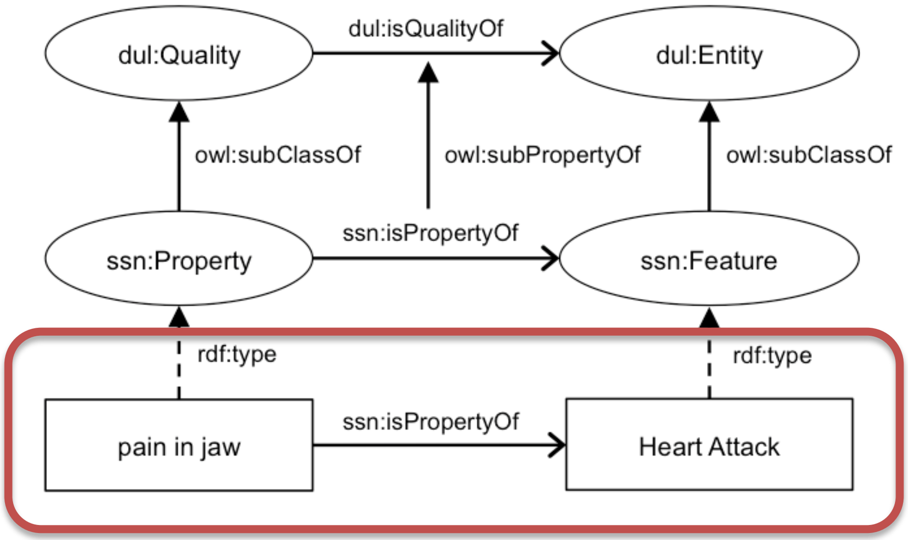
ISWC 2012
The 11th International Semantic Web Conference

The Web is becoming a global knowledge base

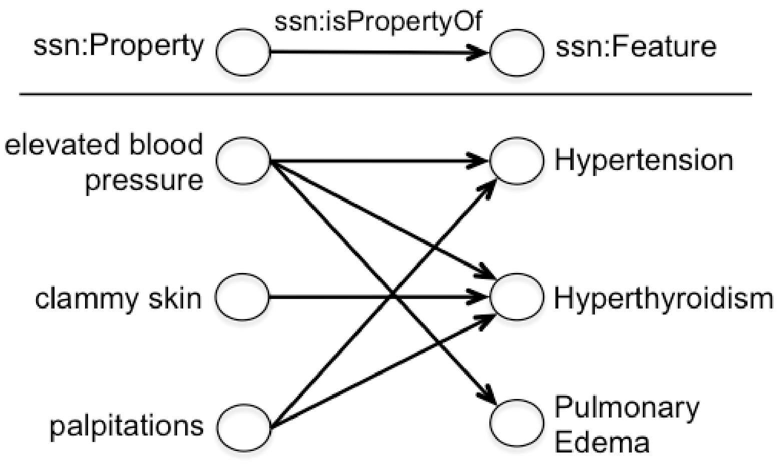
LINKINGOPENDATA
W3C SWEO Community Project

Prior knowledge on the Web

W3C Semantic Sensor Network (SSN) Ontology

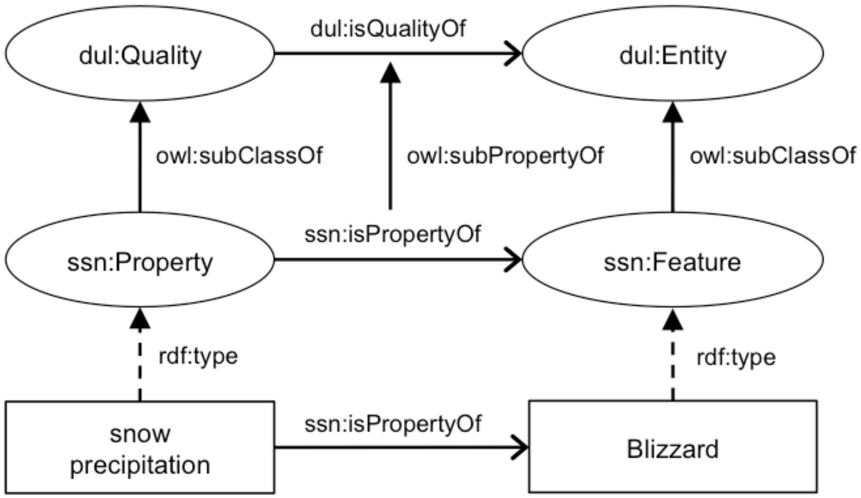


Bi-partite Graph

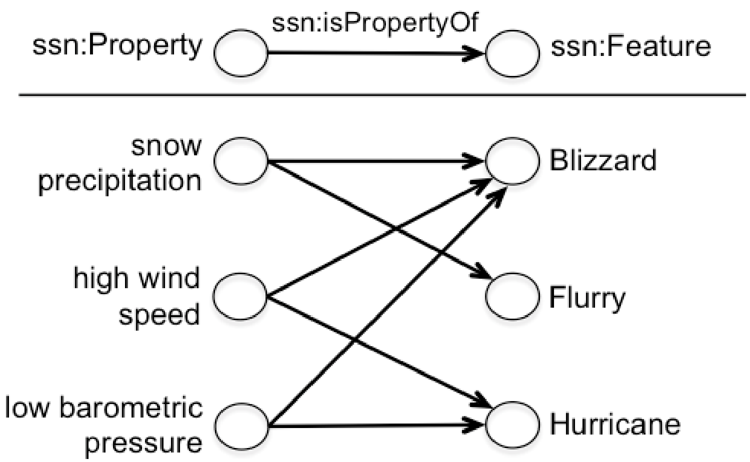


Prior knowledge on the Web

W3C Semantic Sensor Network (SSN) Ontology

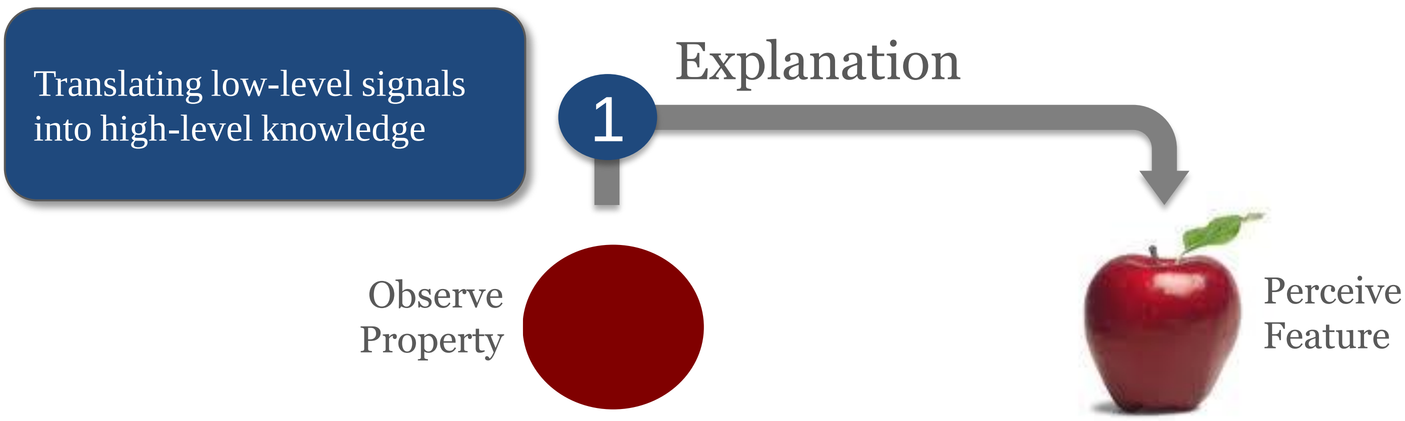


Bi-partite Graph



Explanation

Explanation is the act of choosing the objects or events that best account for a set of observations; often referred to as hypothesis building

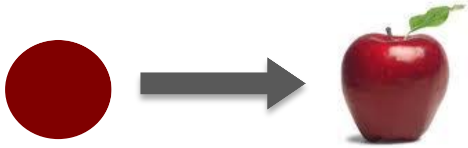


Explanation

Explanation is the act of choosing the objects or events that best account for a set of observations; often referred to as hypothesis building

Inference to the best explanation

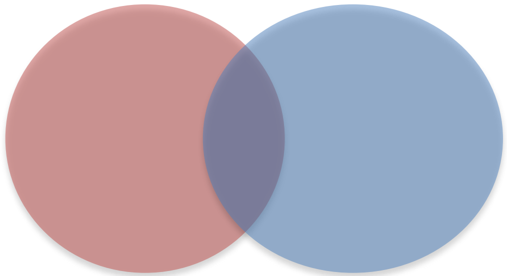
- In general, explanation is an **abductive** problem; and hard to compute



Finding the sweet spot between abduction and OWL

- **Single-feature assumption*** enables use of OWL-DL deductive reasoner

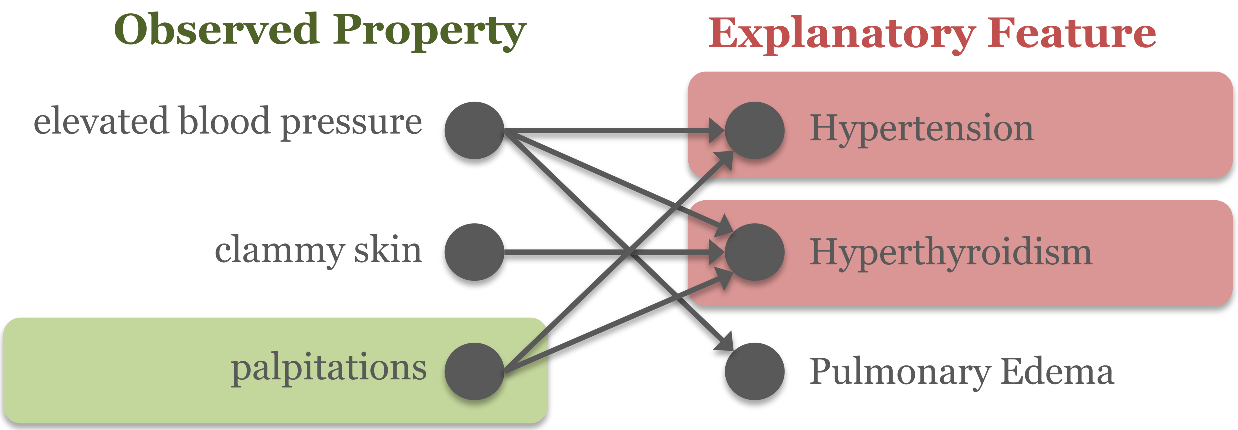
** An explanation must be a single feature which accounts for all observed properties*



Explanation

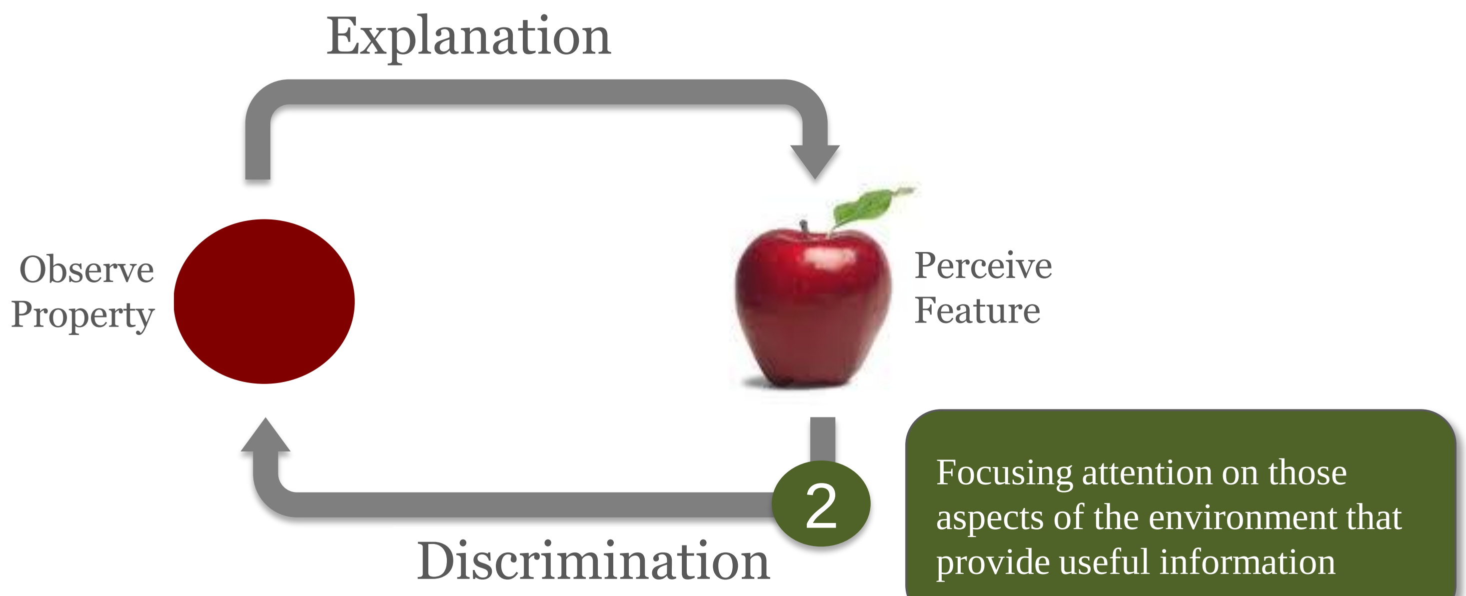
Explanatory Feature: *a feature that explains the set of observed properties*

```
ExplanatoryFeature ≡ ∃ssn:isPropertyOf⁻.{p_1} ⊓ … ⊓ ∃ssn:isPropertyOf⁻.{p_n}
```



Discrimination

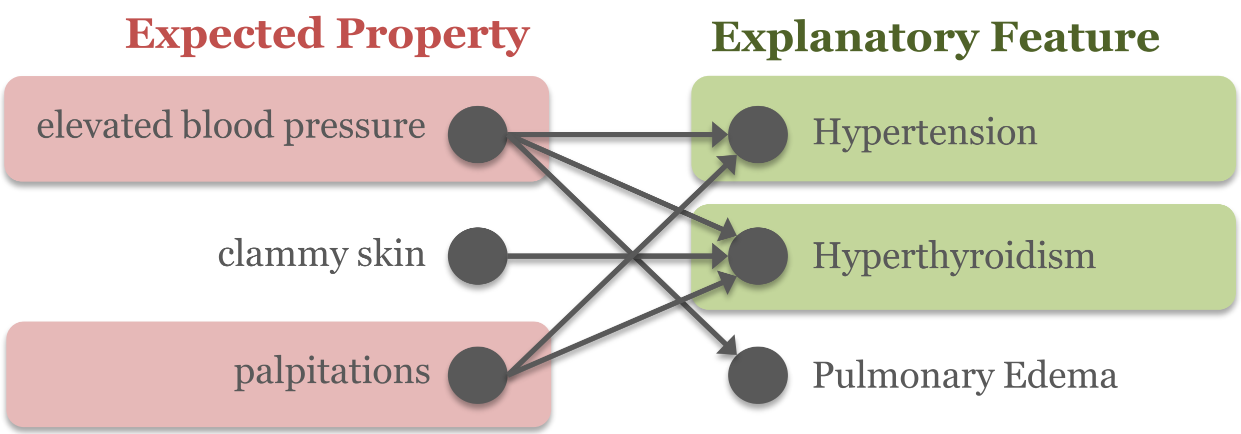
Discrimination is the act of finding those properties that, if observed, would help distinguish between multiple explanatory features



Discrimination

Expected Property: *would be explained by every explanatory feature*

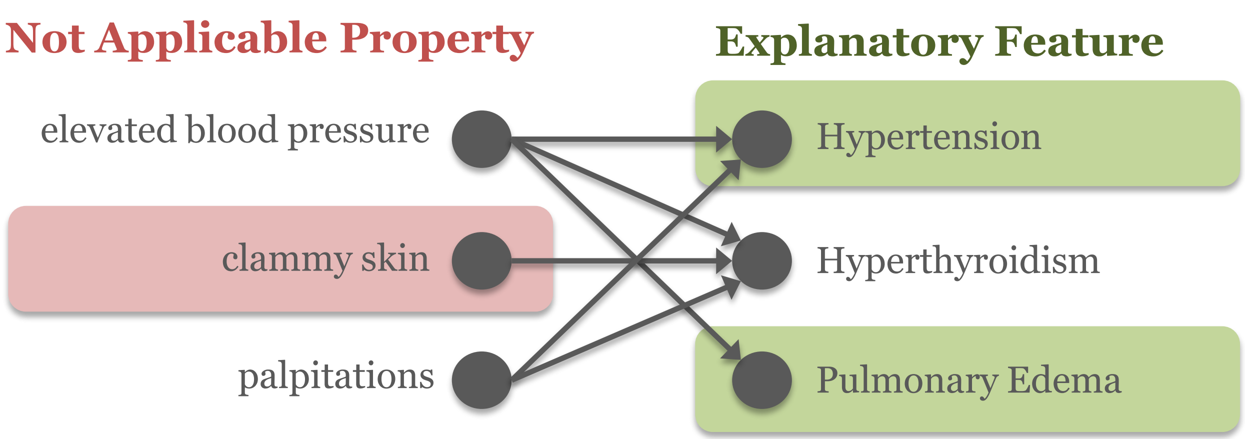
$$\text{ExpectedProperty} \equiv \exists \text{ssn:isPropertyOf}.\{f_1\} \sqcap \ldots \sqcap \exists \text{ssn:isPropertyOf}.\{f_n\}$$



Discrimination

Not Applicable Property: *would not be explained by any explanatory feature*

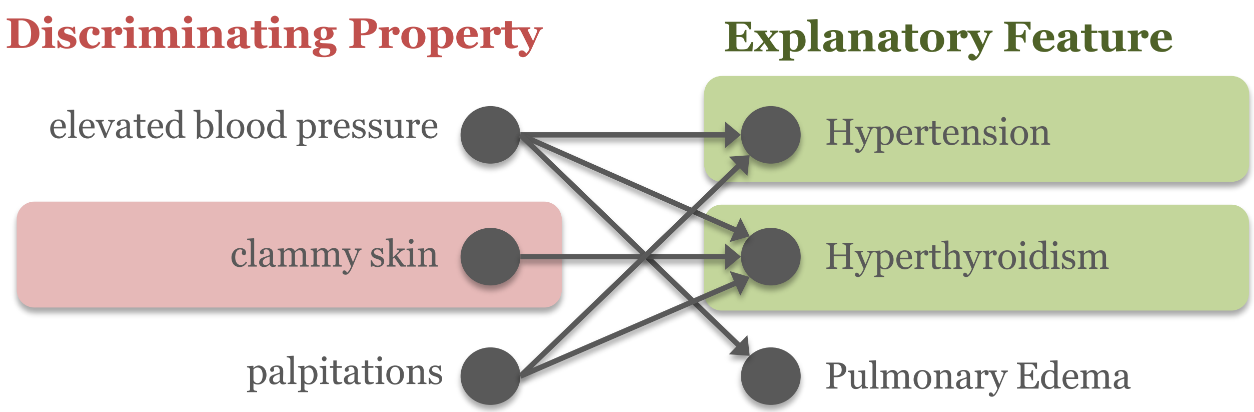
$$\text{NotApplicableProperty} \equiv \neg\exists \text{ssn:isPropertyOf}.\{f_1\} \sqcap \ldots \sqcap \neg\exists \text{ssn:isPropertyOf}.\{f_n\}$$



Discrimination

Discriminating Property: *is neither expected nor not-applicable*

```
DiscriminatingProperty ≡ ¬ExpectedProperty ⊓ ¬NotApplicableProperty
```



Our Motivation

kHealth: knowledge-enabled healthcare

Through physical monitoring and analysis, our cellphones could act as an early warning system to detect serious health conditions

canary in a coal mine

Canary

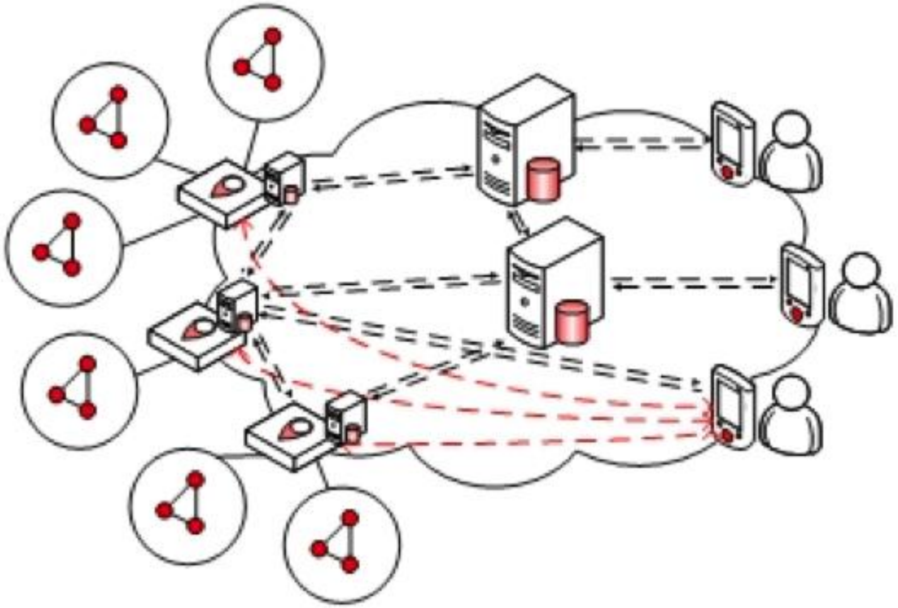
How do we implement machine perception *efficiently* on a resource-constrained device?

Use of OWL reasoner is resource intensive
(especially on resource-constrained devices),
in terms of both memory and time

- Runs out of resources with prior knowledge >> 15 nodes
- Asymptotic complexity: $O(n^3)$

Approach 1: Send all sensor observations to the cloud for processing

Approach 2: downscale semantic processing so that each device is capable of machine perception



intelligence at the edge

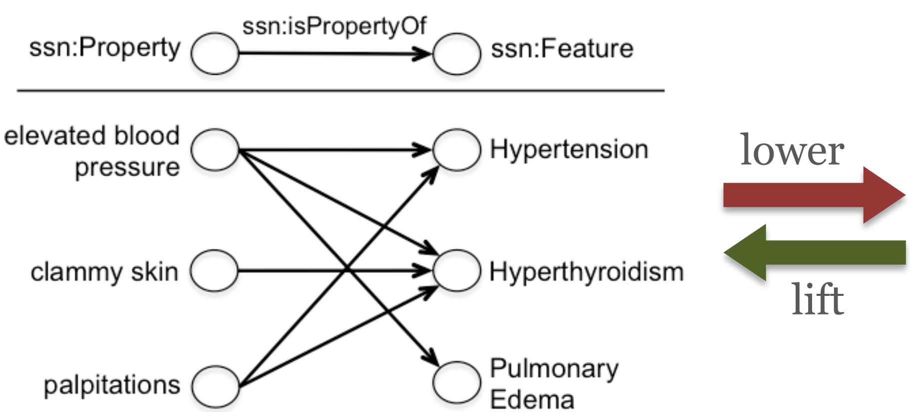
Efficient execution of machine perception

Use *bit vector encodings and their operations* to encode prior knowledge and execute semantic reasoning

010110001101
0011110010101
1000110110110
101100011010
0111100101011
000110101100
0110100111

Lifting and lowering knowledge

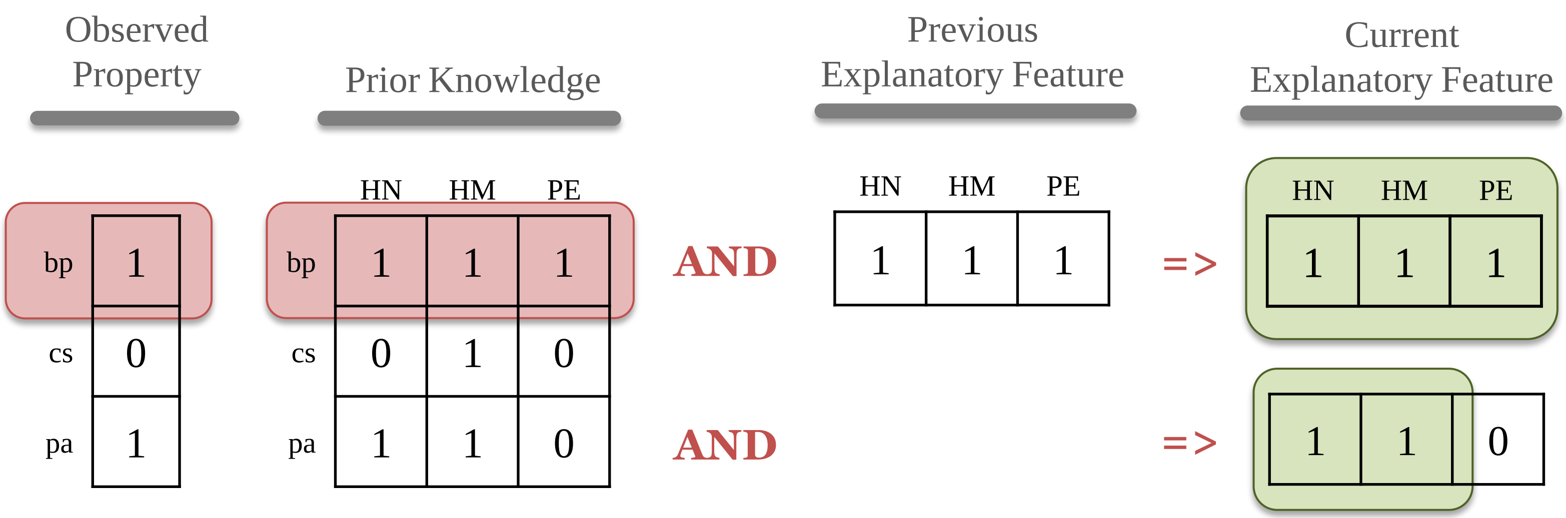
Translate prior knowledge, observations, and explanations between SW and bit vector representation



	Hypertension	Hyperthyroidism	Pulmonary Edema
elevated blood pressure	1	1	1
clammy skin	0	1	0
palpitations	1	1	0

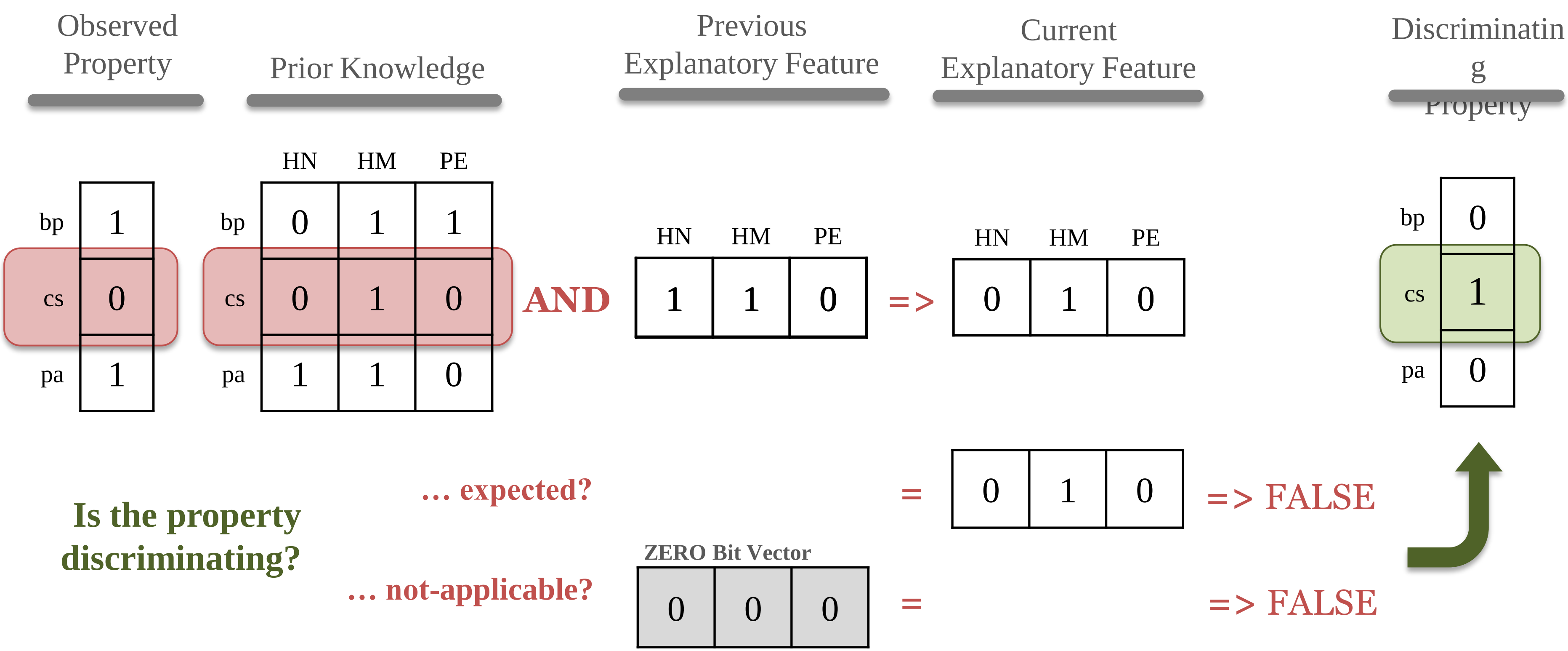
Explanation: efficient algorithm

INTUITION: The strategy employed relies on the use of the bit vector AND operation to discover and dismiss those features that cannot explain the set of observed properties.

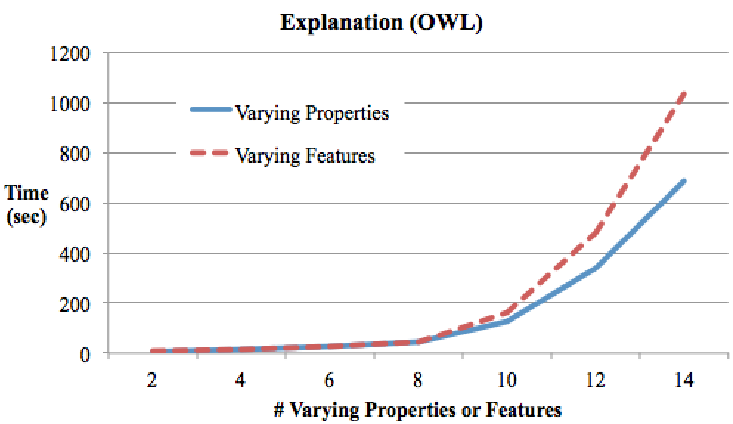


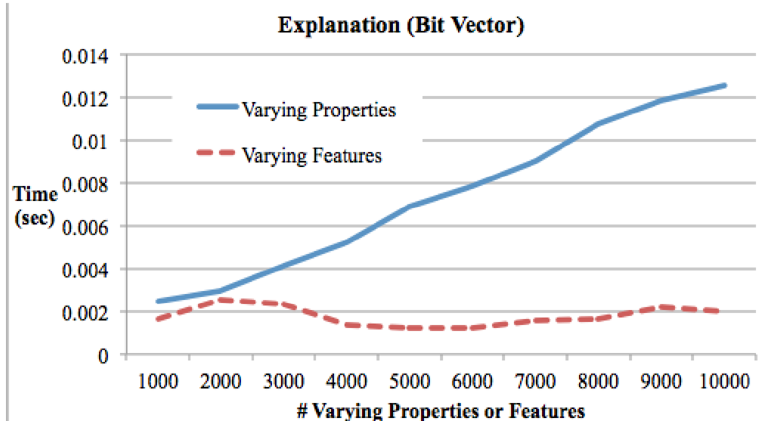
Discrimination: efficient algorithm

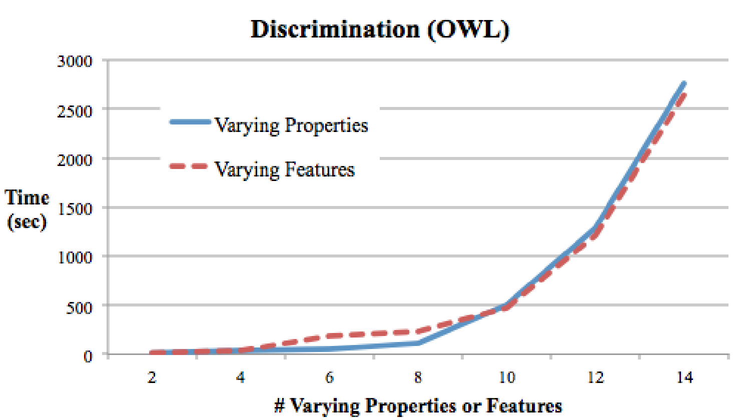
INTUITION: The strategy employed relies on the use of the bit vector AND operation to discover and assemble those features that discriminate between the explanatory features

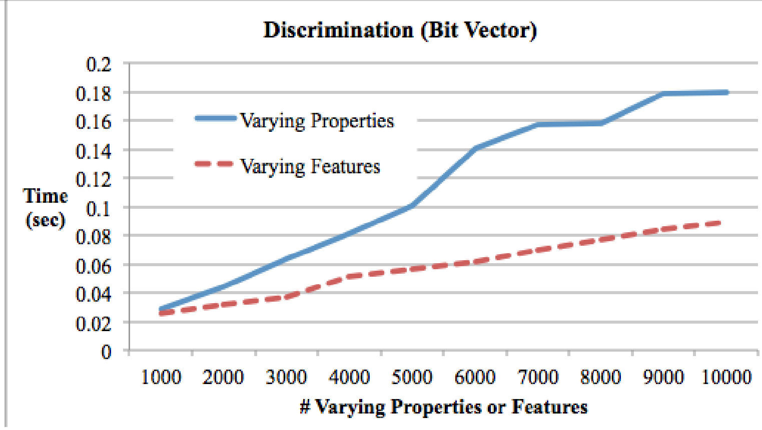


Evaluation on a mobile device

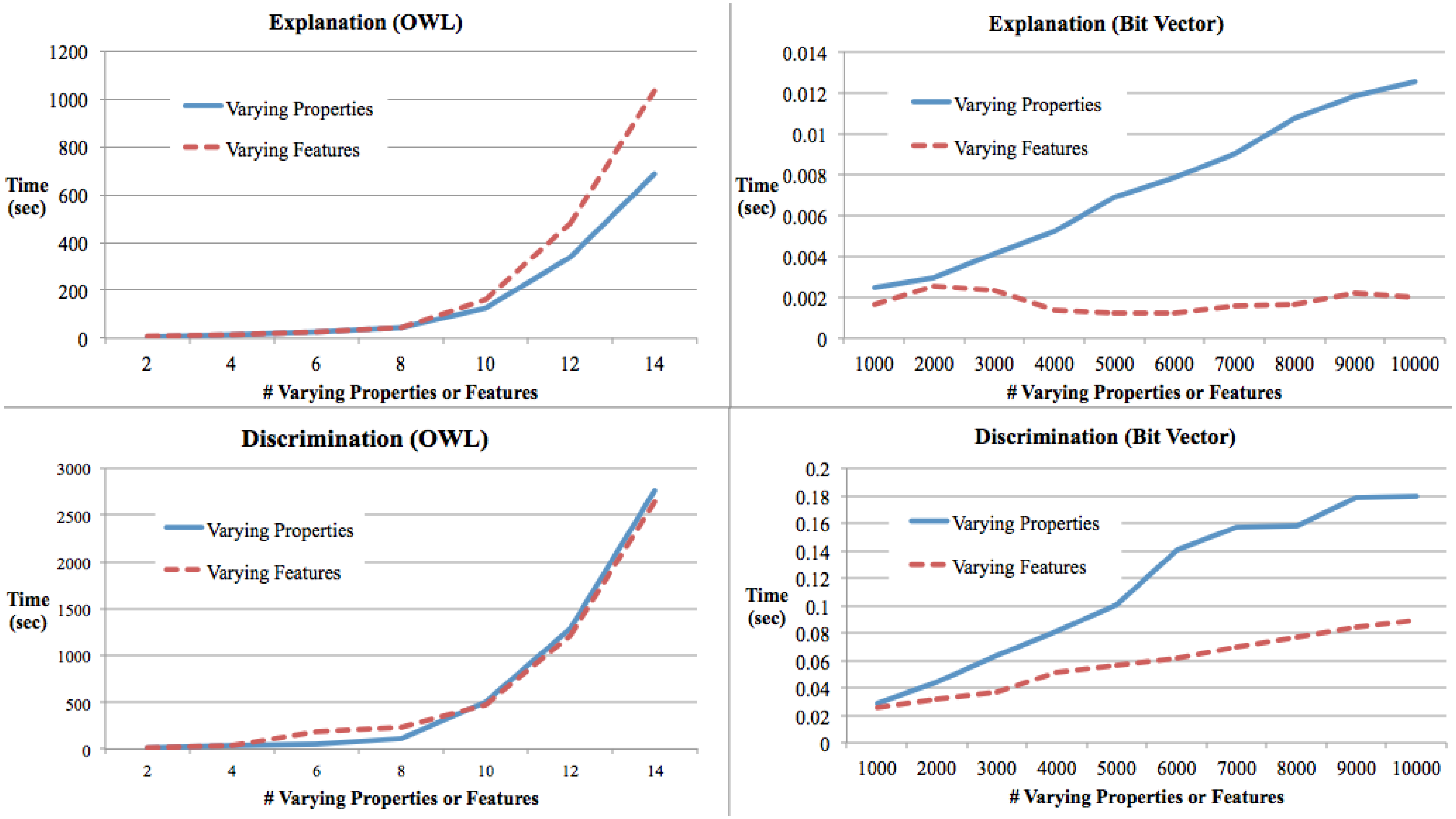








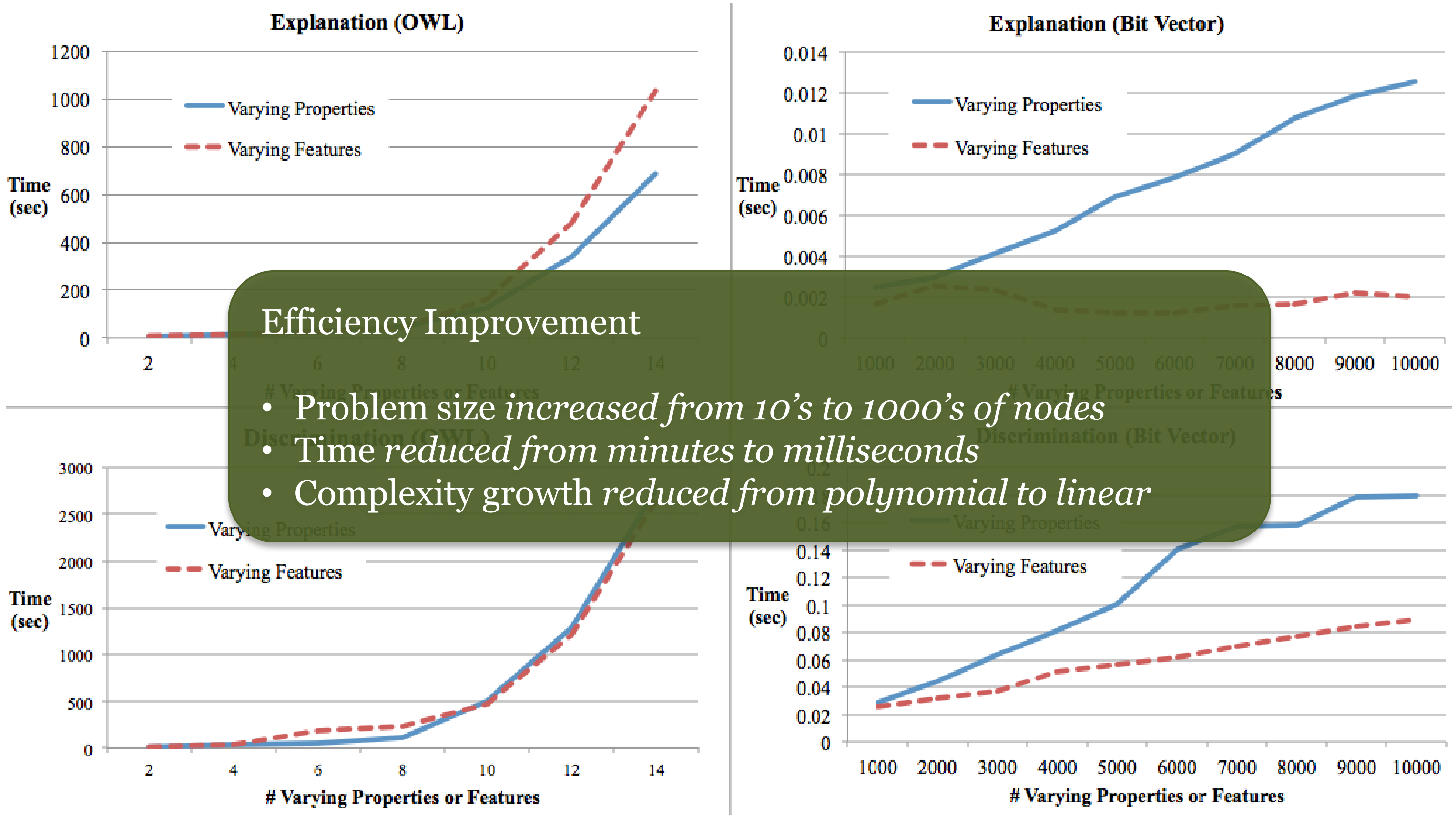
Evaluation on a mobile device



$O(n^3) < x < O(n^4)$

$O(n)$

Evaluation on a mobile device



Efficiency Improvement

- Problem size *increased from 10's to 1000's of nodes*
- Time *reduced from minutes to milliseconds*
- Complexity growth *reduced from polynomial to linear*

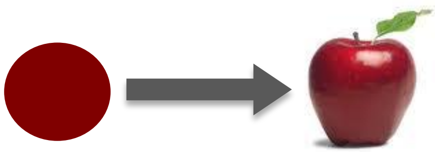
$O(n^3) < x < O(n^4)$

$O(n)$

3 ideas to takeaway

1 *Translate low-level data to high-level knowledge*

Machine perception can be used to convert low-level sensory signals into high-level knowledge useful for decision making



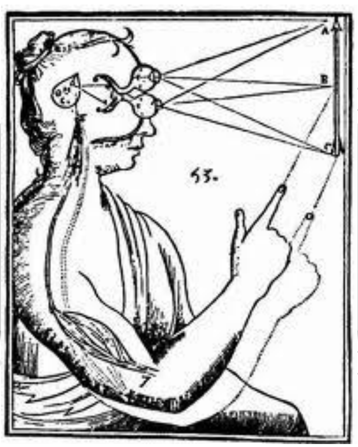
2 *Prior knowledge is the key to perception*

Using SW technologies, machine perception can be formalized and integrated with prior knowledge on the Web

3 *Intelligence at the edge*

By downscaling semantic inference, machine perception can execute efficiently on resource-constrained devices

Thank you.



01 …0010101100011011011010110001101001110010101100011010110001101001111

An Efficient Bit Vector Approach to Semantics-based Machine Perception in Resource-constrained Devices

01 …0010101100011011011010110001101001110010101100011010110001101001111

Cory Henson, Krishnaprasad Thirunarayan, Amit Sheth
Kno.e.sis – Ohio Center of Excellence in Knowledge-enabled Computing