Cognitive Computing

Dr. Piyush Joshi

Assistant Professor

IIIT Sri City

AI but **not** Real AI

- Current AI not follow what the original field was supposed to be about…..

AI but **not** Real AI

- We do not have flexible general-purpose notion of intelligence.

- We can do many things but why **AI is specific**.

- **Where is the gap?**

Where's the gap?

- Intelligence is not just about *pattern recognition* and *function approximation*.
- It is about *modeling the world*…
  – *explaining* and *understanding* what we see.
  – *imagining* things we could see but haven't yet.
  – *planning* actions and *solving problems* to make these things real.
  – *building new models* as we learn more about the world.
  – *sharing our models* to grow knowledge socially and culturally.

Lake, Ullman, Tenenbaum & Gershman, "Building machines that learn and think like people", on arXiv and *Behavioral and Brain Sciences* (2017).

Scene Understanding

"The state of Computer Vision: We are really, really far away"

Source: http://karpathy.github.io

- Complete understanding an image has always been the ultimate goal of Computer Vision, since its inception.
- On viewing this image to the left, we, humans can easily deduce the story behind it.
- Machines have yet to form their "understanding" of context from an image.

Intelligent ?

Imagine if we could build a machine that grows into intelligence the way a human being does – that starts like a baby, and learns like a child.

Intelligent by Alan Turing

MIND
A QUARTERLY REVIEW
[October, 1950

COMPUTING MACHINERY AND INTELLIGENCE

By A. M. Turing

In the process of trying to imitate an adult human mind we are bound to think a good deal about the process which has brought it to the state that it is in. We may notice three components,

(a) The initial state of the mind, say at birth,
(b) The education to which it has been subjected,
(c) Other experience, not to be described as education, to which it has been subjected.

Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child-brain is something like a note-book as one buys it from the stationers. Rather little mechanism, and lots of blank sheets.

"Presumably the child-brain is something like a note-book as one buys it from the stationers. Rather little mechanism, and lots of blank sheets."

Really cars learning ?

- We have big name self-driving cars such as Tesla, Waymo etc.
- Waymo taxi available in phoenix.

Self-driving cars

- Two things are very important:
- 1) How much has been invested in building these cars
- 2) How far we are from actual full self-driving cars- like humans do

- An article in **wall street journal** on business side:
  - $100 billion investment
  - We are far from the end

- People are working in industry for at least 15 years
- And in academia since 80s

CMU: Self-driving cars

- Mid 80s: CMU built self-driving car
- This car is guided by as simple neural network.
- So porotype you see today have existed for many year.

Current status of Self-driving cars

- Still despite many years, $100 billion and work by world's greatest engineering company like Google and Tesla
- We are still far from having complete solution to full self-driving car (like human do).

The New York Times

The Costly Pursuit of Self-Driving Cars Continues On. And On. And On.

Many in Silicon Valley promised that self-driving cars would be a common sight by 2021. Now the industry is resetting expectations and settling in for years of more work.

Current status of Self-driving cars

By Cade Metz

Published May 24, 2021   Updated Sept. 15, 2021

It was seven years ago when Waymo discovered that spring blossoms made its self-driving cars get twitchy on the brakes. So did soap bubbles. And road flares.

New tests, in years of tests, revealed more and more distractions for the driverless cars. Their road skills improved, but matching the competence of human drivers was elusive. The cluttered roads of America, it turned out, were a daunting place for a robot.

Current status of Self-driving cars

The New York Times

The Costly Pursuit of Self-Driving Cars Continues On. And On. And On.

Many in Silicon Valley promised that self-driving cars would be a common sight by 2021. Now the industry is resetting expectations and settling in for years of more work.

Self-driving tech is not yet nimble enough to reliably handle the variety of situations human drivers encounter each day. It can usually handle suburban Phoenix, but it can't duplicate the human chutzpah needed for merging into the Lincoln Tunnel in New York or dashing for an offramp on Highway 101 in Los Angeles.

"You have to peel back every layer before you can see the next layer" of challenges for the technology, said Nathaniel Fairfield, a Waymo software engineer who has worked on the project since 2009, describing some of the distractions faced by the cars. "Your car has to be pretty good at driving before you can really get it into the situations where it handles the next most challenging thing."

What’s missing from the current ML paradigm

Must be able to generalize to an infinite range of new tasks with *essentially no re-training or fine-tuning.*

The common-sense core

The common-sense core

Human thought is structured around a basic understanding of physical objects and substances, intentional agents, and their interactions – “intuitive theories”, or abstract systems of knowledge, about **physics** (forces, masses…) and **psychology** (desires, beliefs, plans…)

Develop early in infancy

Shared to some extent with other species

Implemented in functionally distinct brain systems

The bridge between perception, language, and action planning

Intuitive Physics: common-sense

Common-sense

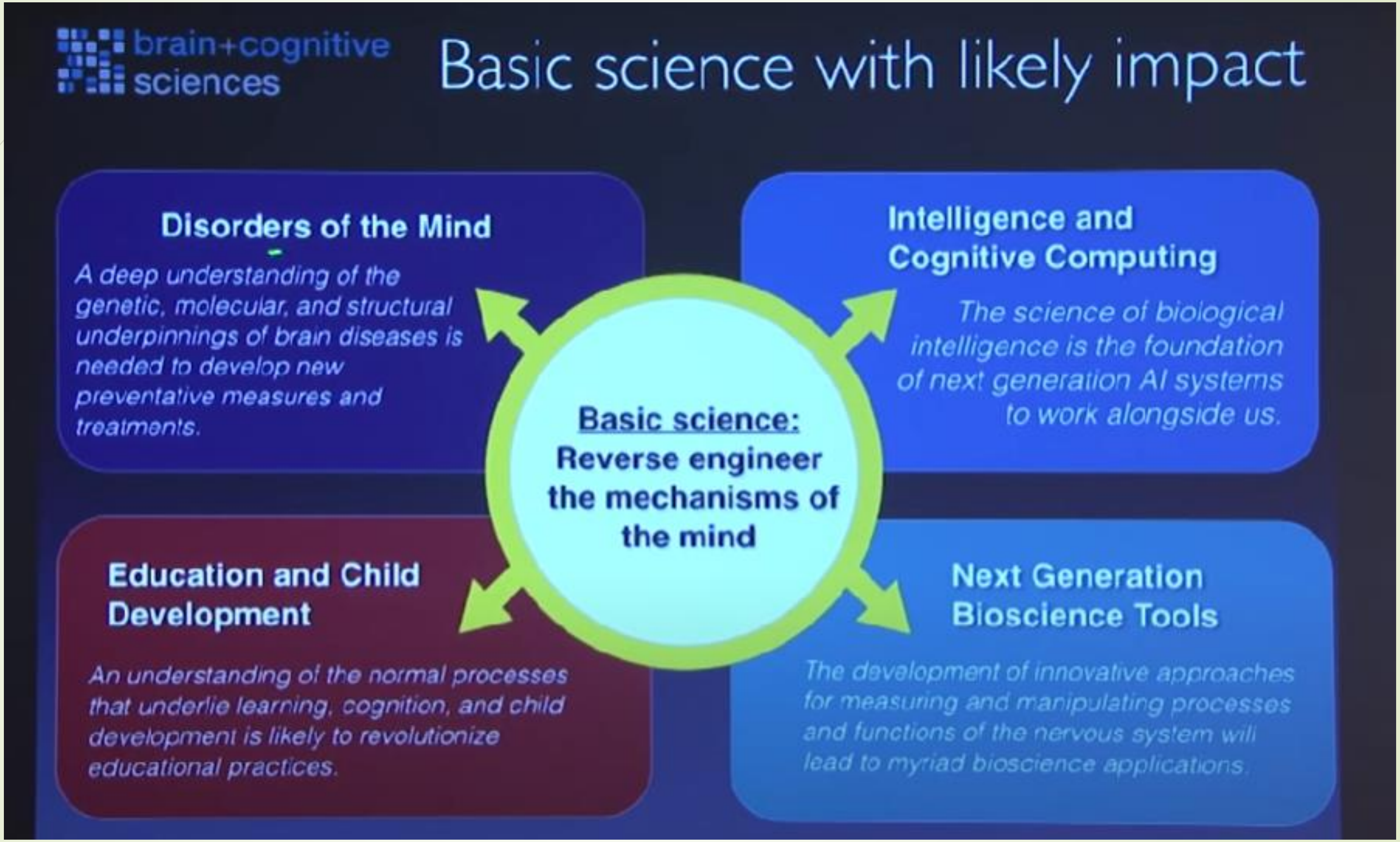
Common-sense

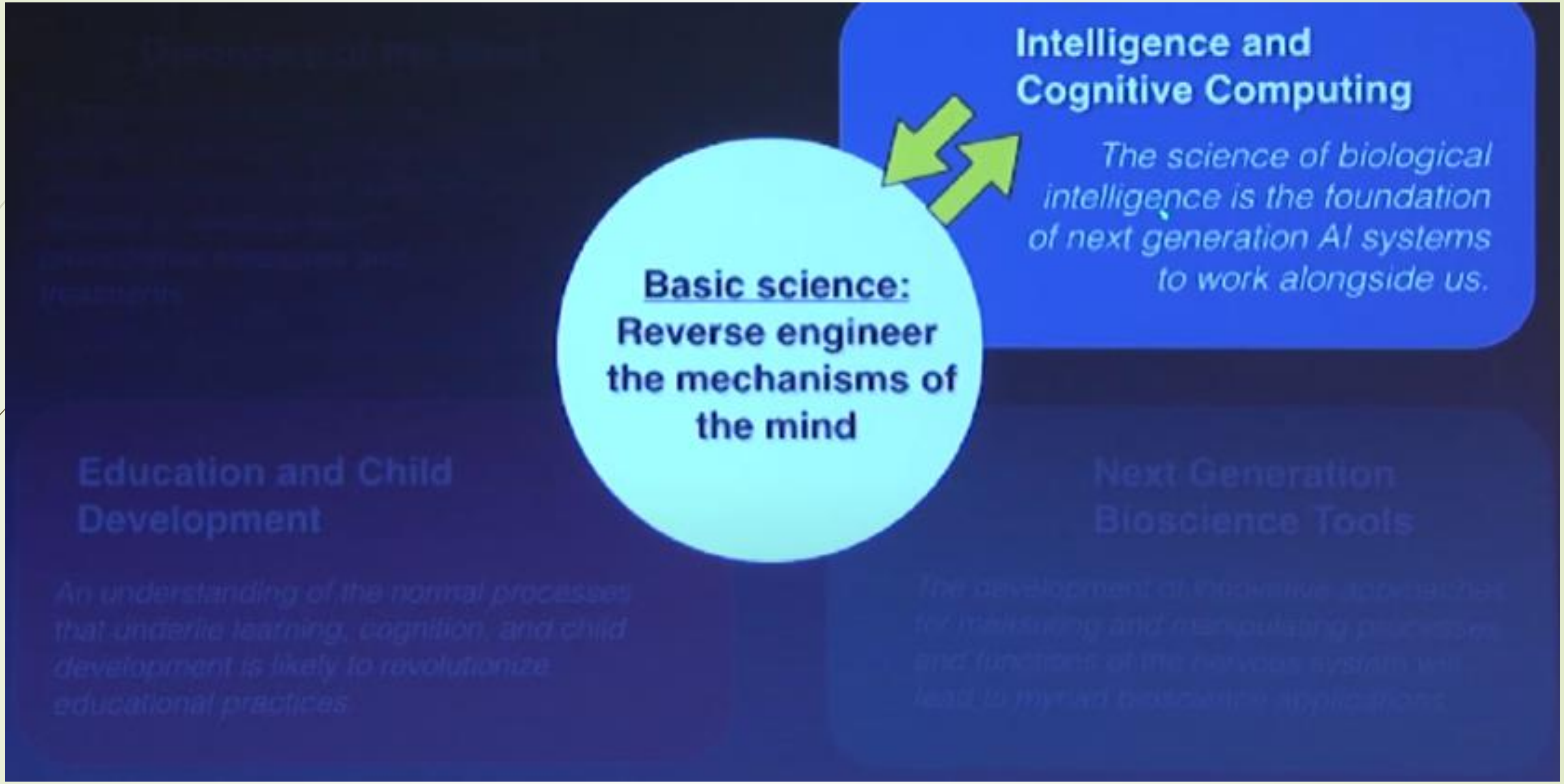
What's missing from the current ML paradigm

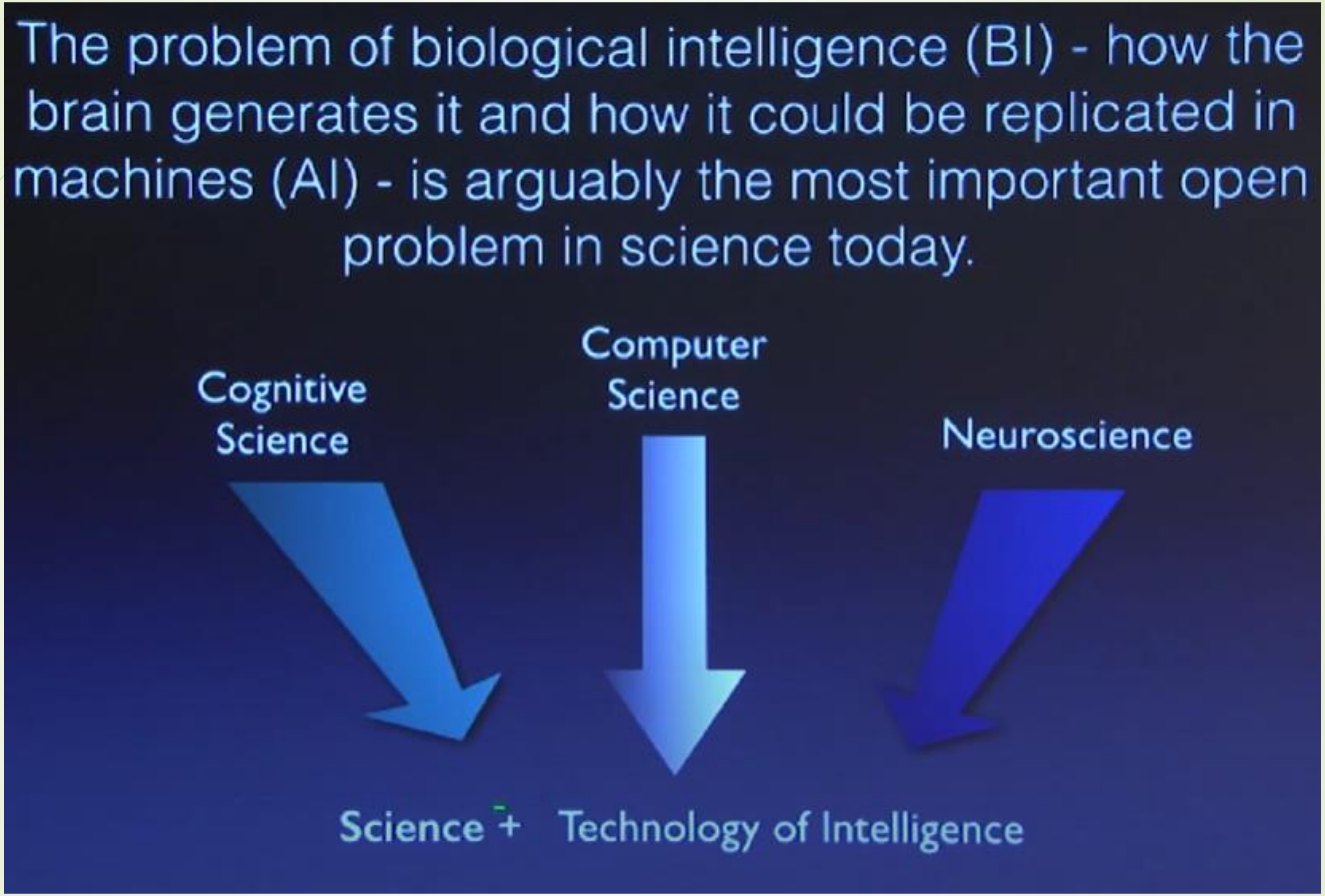
Must be able to generalize to environments vastly different from training sets with *essentially no re-training or fine-tuning.*




Reverse Engineering


brain+cognitive sciences
Basic science with likely impact
Disorders of the Mind
A deep understanding of the genetic, molecular, and structural underpinnings of brain diseases is needed to develop new preventative measures and treatments.
Intelligence and Cognitive Computing
The science of biological intelligence is the foundation of next generation AI systems to work alongside us.
Basic science:
Reverse engineer the mechanisms of the mind
Education and Child Development
An understanding of the normal processes that underlie learning, cognition, and child development is likely to revolutionize educational practices.
Next Generation Bioscience Tools
The development of innovative approaches for measuring and manipulating processes and functions of the nervous system will lead to myriad bioscience applications.


Intelligence and Cognitive Computing
The science of biological intelligence is the foundation of next generation AI systems to work alongside us.
Basic science:
Reverse engineer the mechanisms of the mind
Education and Child Development
An understanding of the normal processes that underlie learning, cognition, and child development is likely to revolutionize educational practices
Next Generation Bioscience Tools


The problem of biological intelligence (BI) - how the brain generates it and how it could be replicated in machines (AI) - is arguably the most important open problem in science today.
Cognitive Science
Computer Science
Neuroscience
Science + Technology of Intelligence

Biological intelligence ("the mind") has many facets:

- Visual comprehension
- Audio and speech comprehension
- Navigation and route planning
- Decision making
- Modeling other minds (social behavior)
- ...

- Learning each of the above from limited data

WHAT IS REVERSE ENGINEERING THE BRAIN?

- Reverse engineer- to study or analyze in order to learn details of design, construction, and operation, perhaps to produce a copy or an improved version.
- Linking the dynamics of neural circuits to behavior.
- The operational principles of a neural circuit must be deduced through analysis of its structure and function.
- Basically figuring out how the living brain works.

PURPOSE

- Scientists can simulate the brains activities and gain insight about how and why the brain works and fails.
- Scientists will be able to test potential biotechnology solutions to brain disorders, such as drugs or neural implants.
- Increased computing capability will allow computers to simulate reality.
- Computers will be able to process multiple streams of information in parallel rather than the one step at a time.

APPLICATIONS

- AI algorithms used in speech recognition and in machine vision systems.
- Cochlear implants
- Stimulating electrodes to treat Parkinson's disease
- Devices that can enter the body to perform medical diagnoses and treatments.
- Brain controlled artificial limbs.

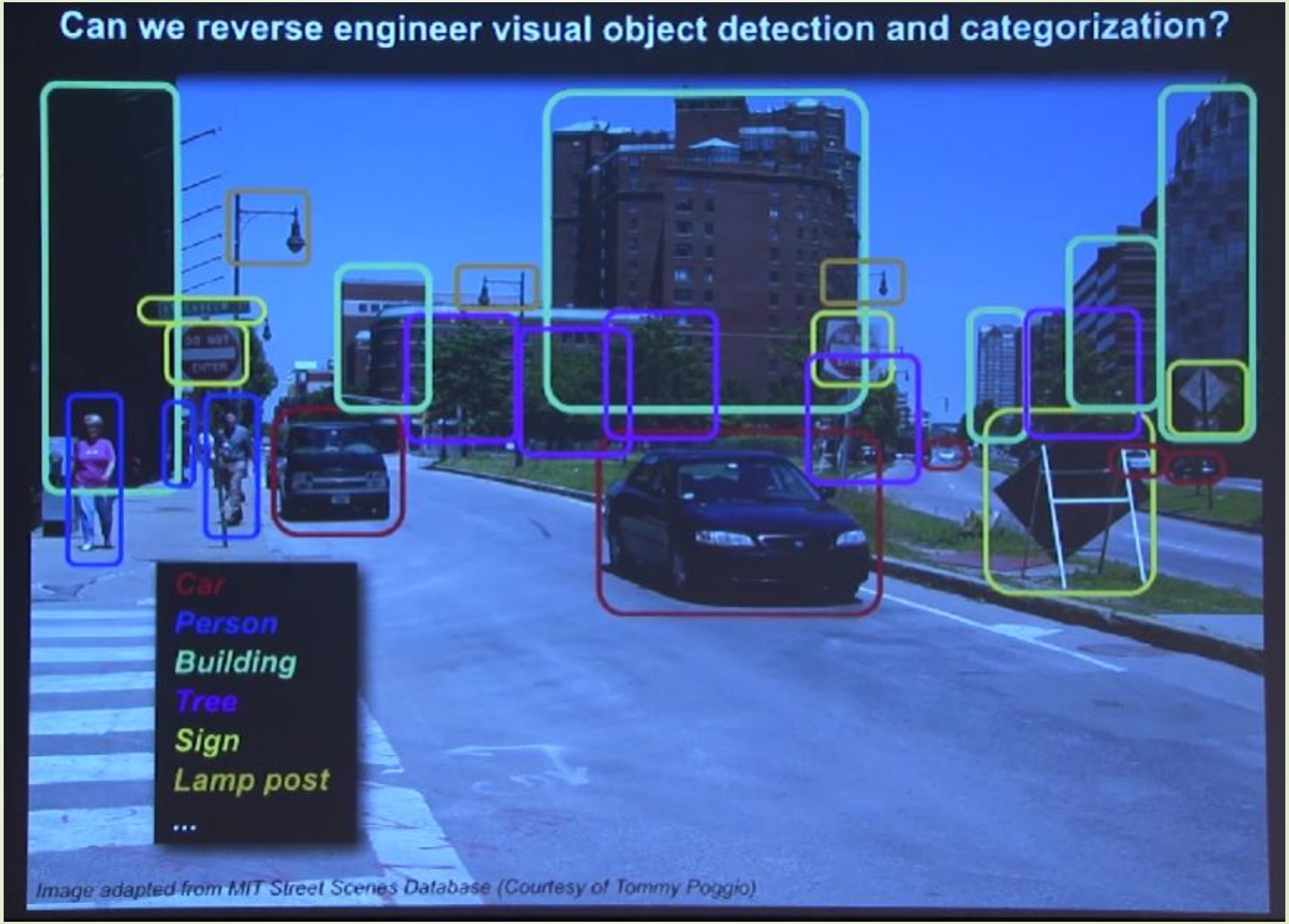
CHALLENGES

- Scientists must study the brain while being noninvasive.
- Each nerve cell receives messages from tens of thousands of others making it difficult to trace the signaling pathways.
- Nerve cells fire at different rates making the code complex.
- The electronic logic gates of computers are either on or off but neurons assume various levels of excitation.

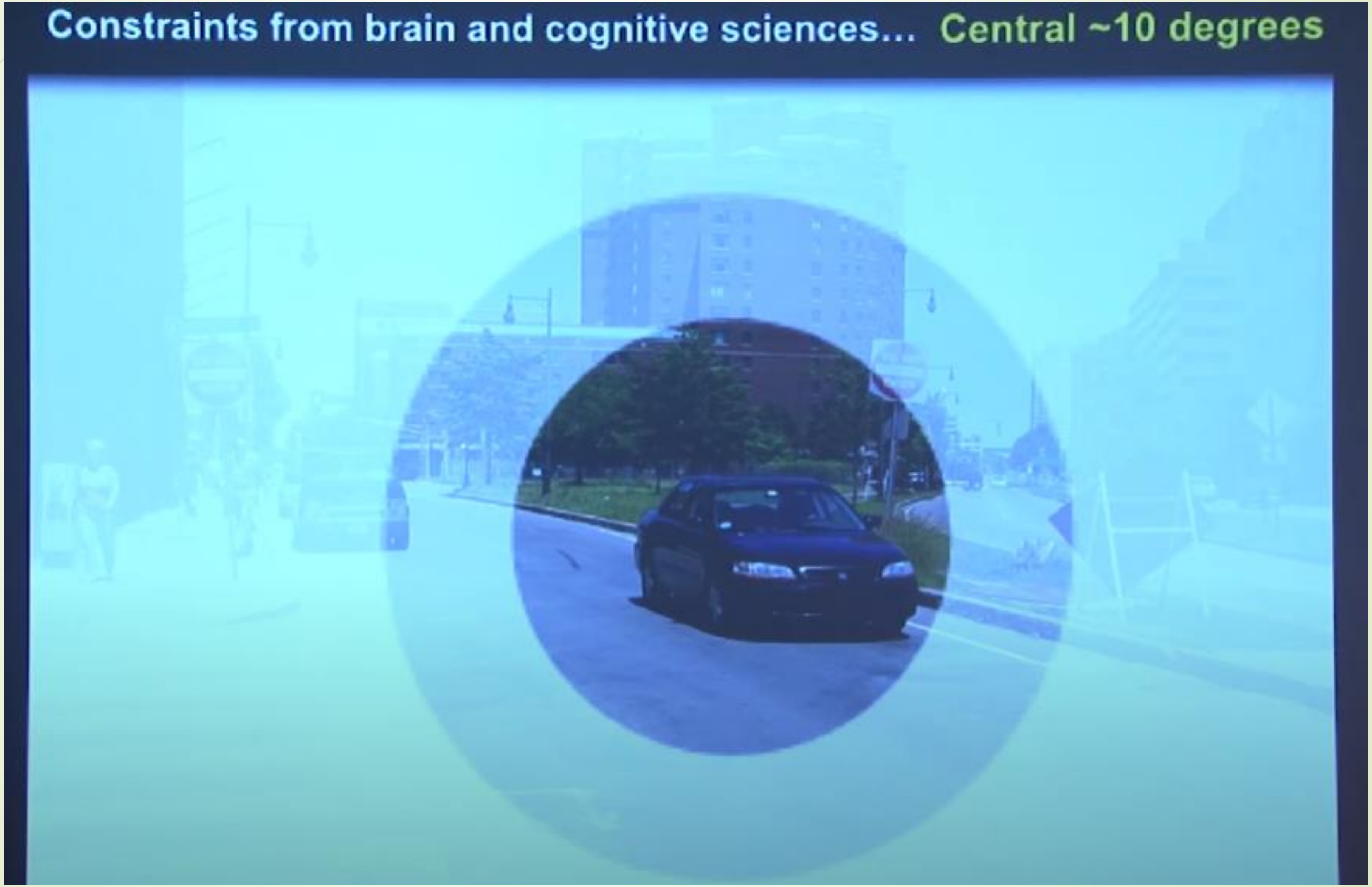
Human minds have “strong perception.”

Image adapted from MIT Street Scenes Database (Courtesy of Tommy Poggio)


Can we reverse engineer visual object detection and categorization?
DO NOT ENTER
Image adapted from MIT Street Scenes Database (Courtesy of Tommy Poggio)


Can we reverse engineer visual object detection and categorization?
Car
Person
Building
Tree
Sign
Lamp post
...
Image adapted from MIT Street Scenes Database (Courtesy of Tommy Poggio)

Brain does not process whole image at once



Steps needed to reverse engineer: Core object perception

central ~10 deg of visual field

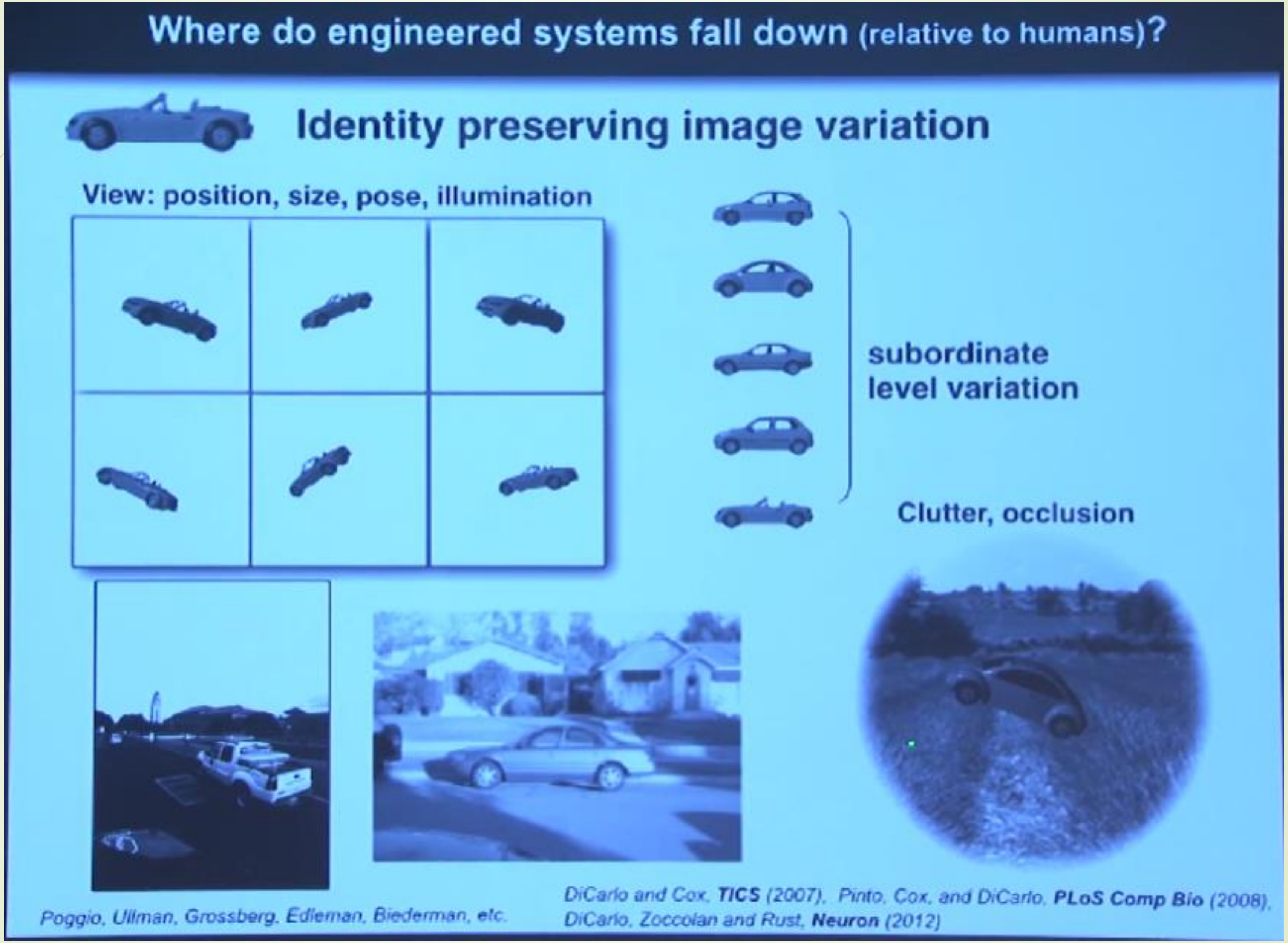
~0.2 second viewing duration

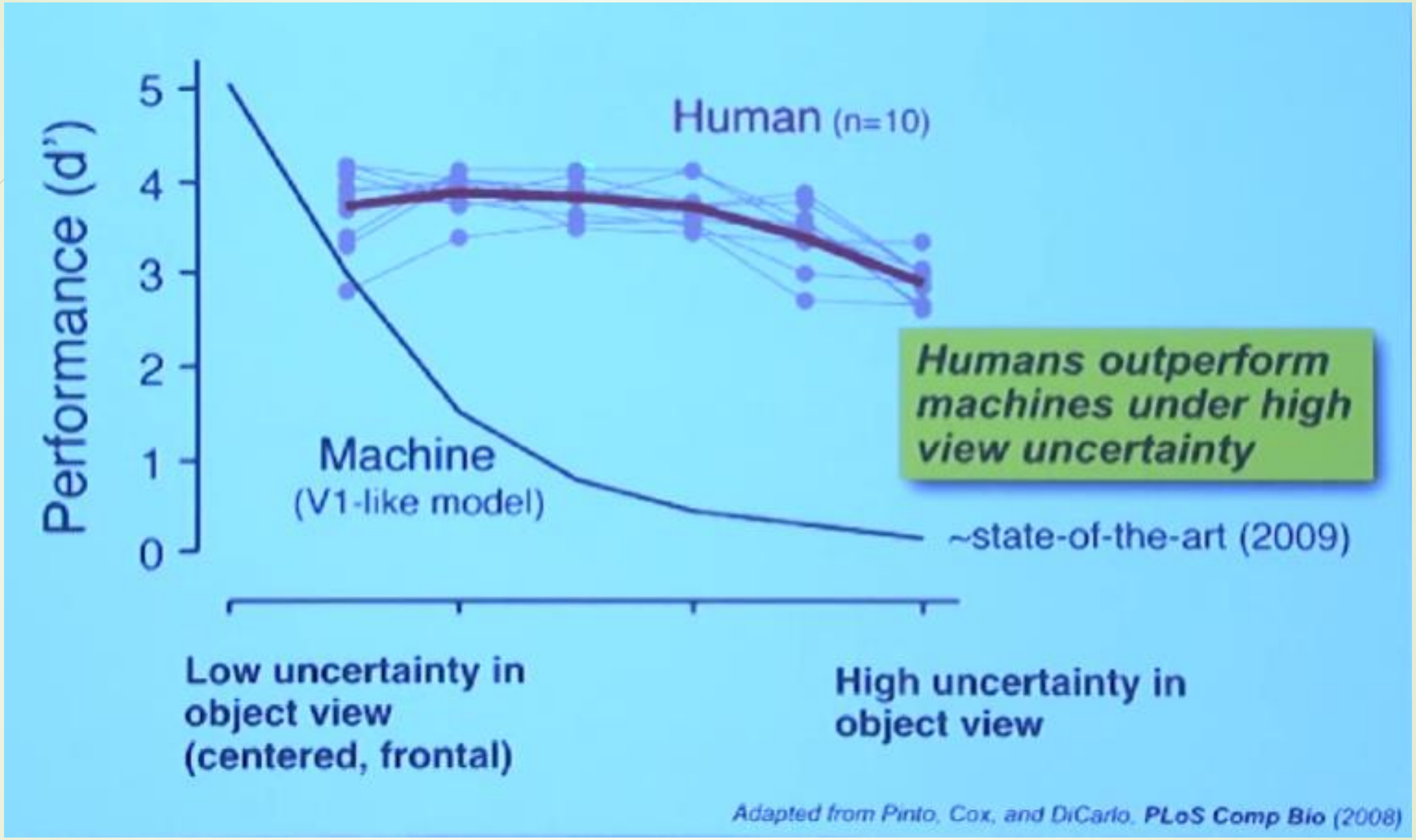
Where do currently* engineered systems fall down (relative to biological brains)?

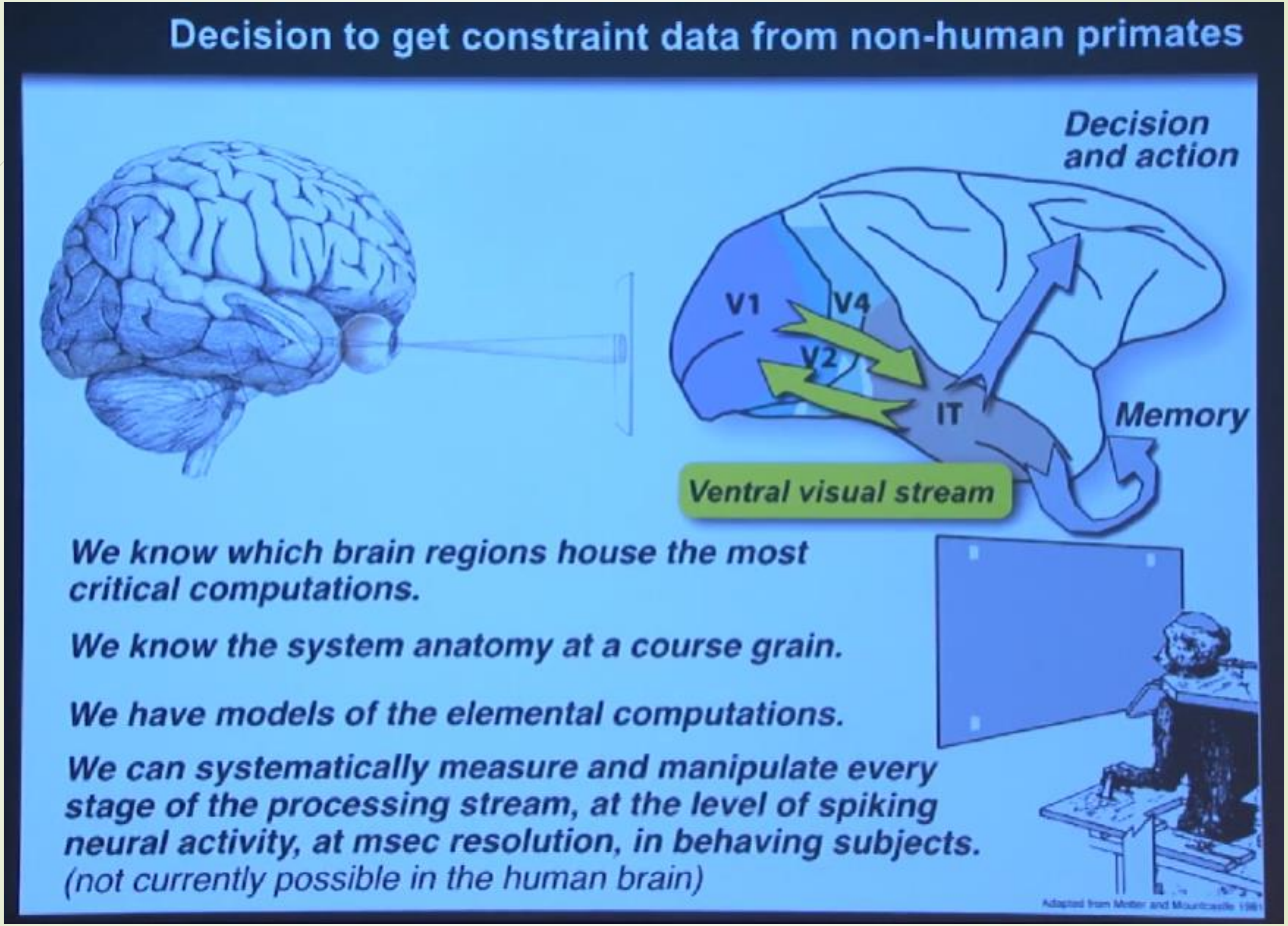
Which brain measurements are likely to be most informative?

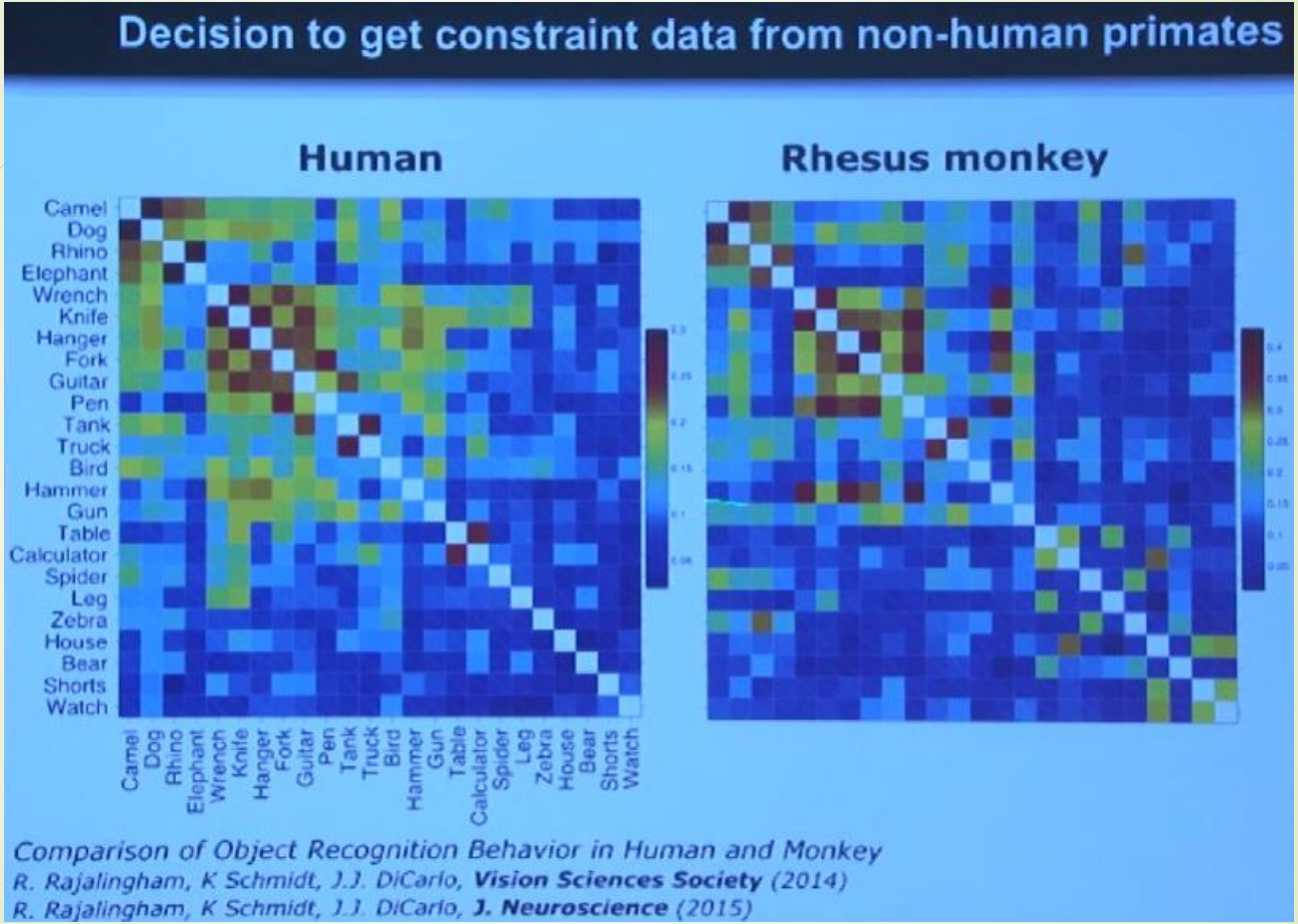
(behavior, blood flow, neural activity, anatomy, neural perturbation, sub-cellular, genetics, etc.)

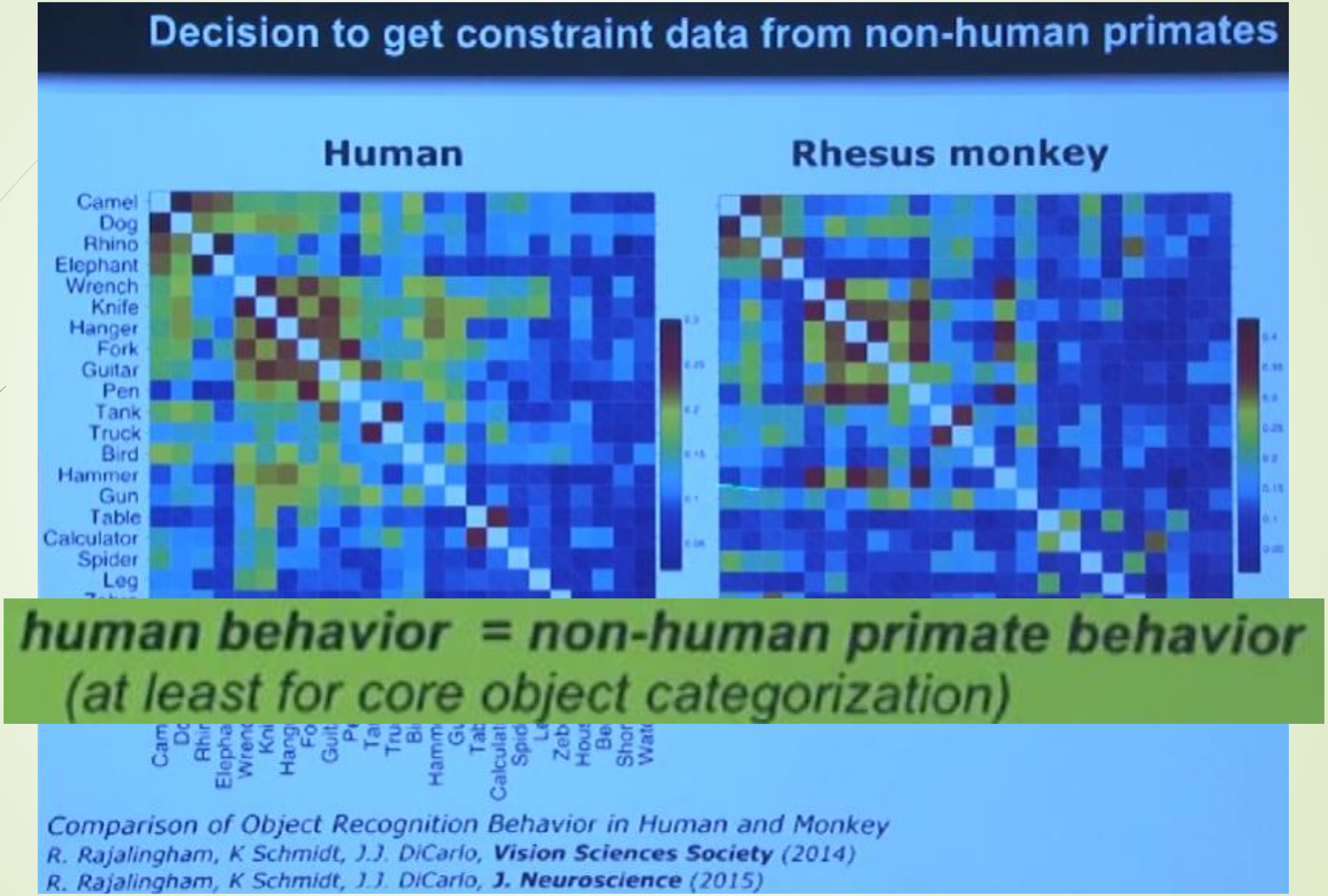
How do we forward engineer using such measurements?

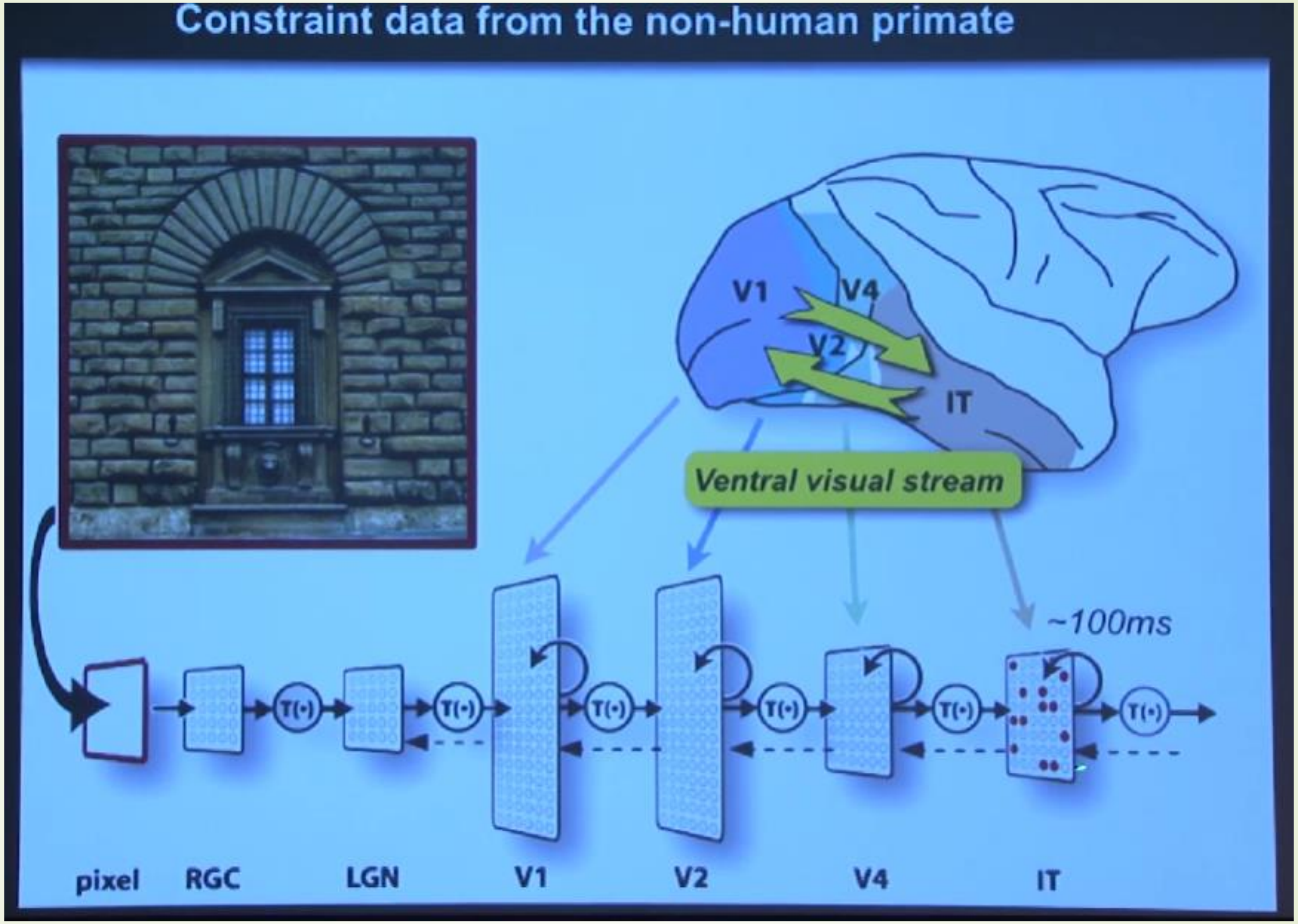

Where do engineered systems fall down (relative to humans)?
Identity preserving image variation
View: position, size, pose, illumination
subordinate
level variation
Clutter, occlusion
Poggio, Ullman, Grossberg, Edleman, Biederman, etc.
DiCarlo and Cox, TICS (2007), Pinto, Cox, and DiCarlo, PLoS Comp Bio (2008),
DiCarlo, Zoccolan and Rust, Neuron (2012)


Performance (d')
5
4
3
2
1
0
Human (n=10)
Machine
(V1-like model)
~state-of-the-art (2009)
Humans outperform machines under high view uncertainty
Low uncertainty in object view (centered, frontal)
High uncertainty in object view
Adapted from Pinto, Cox, and DiCarlo, PLoS Comp Bio (2008)

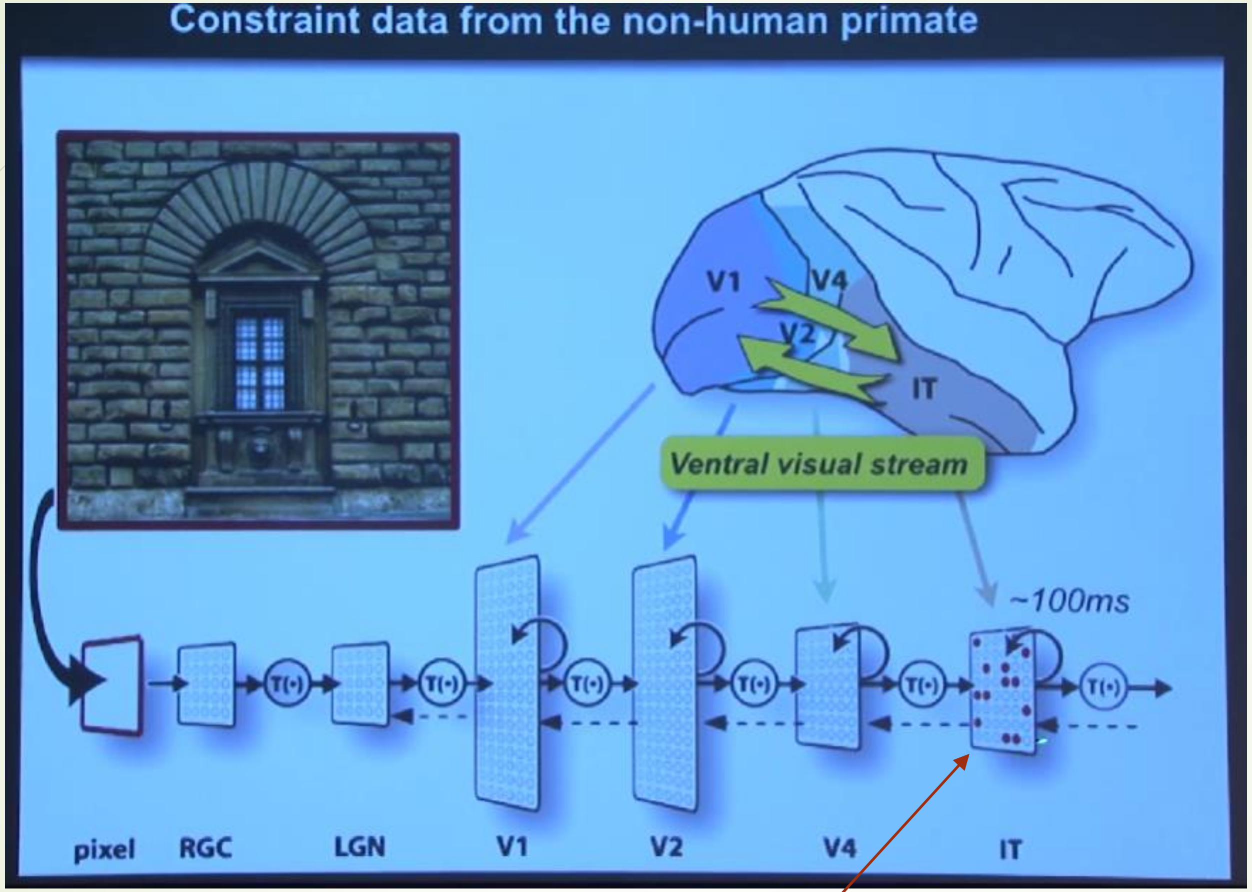

Decision to get constraint data from non-human primates
Decision and action
V1
V4
V2
IT
Memory
Ventral visual stream
We know which brain regions house the most critical computations.
We know the system anatomy at a course grain.
We have models of the elemental computations.
We can systematically measure and manipulate every stage of the processing stream, at the level of spiking neural activity, at msec resolution, in behaving subjects.
(not currently possible in the human brain)


Decision to get constraint data from non-human primates
Human
Rhesus monkey
Camel
Dog
Rhino
Elephant
Wrench
Knife
Hanger
Fork
Guitar
Pen
Tank
Truck
Bird
Hammer
Gun
Table
Calculator
Spider
Leg
Zebra
House
Bear
Shorts
Watch
Comparison of Object Recognition Behavior in Human and Monkey
R. Rajalingham, K Schmidt, J.J. DiCarlo, Vision Sciences Society (2014)
R. Rajalingham, K Schmidt, J.J. DiCarlo, J. Neuroscience (2015)

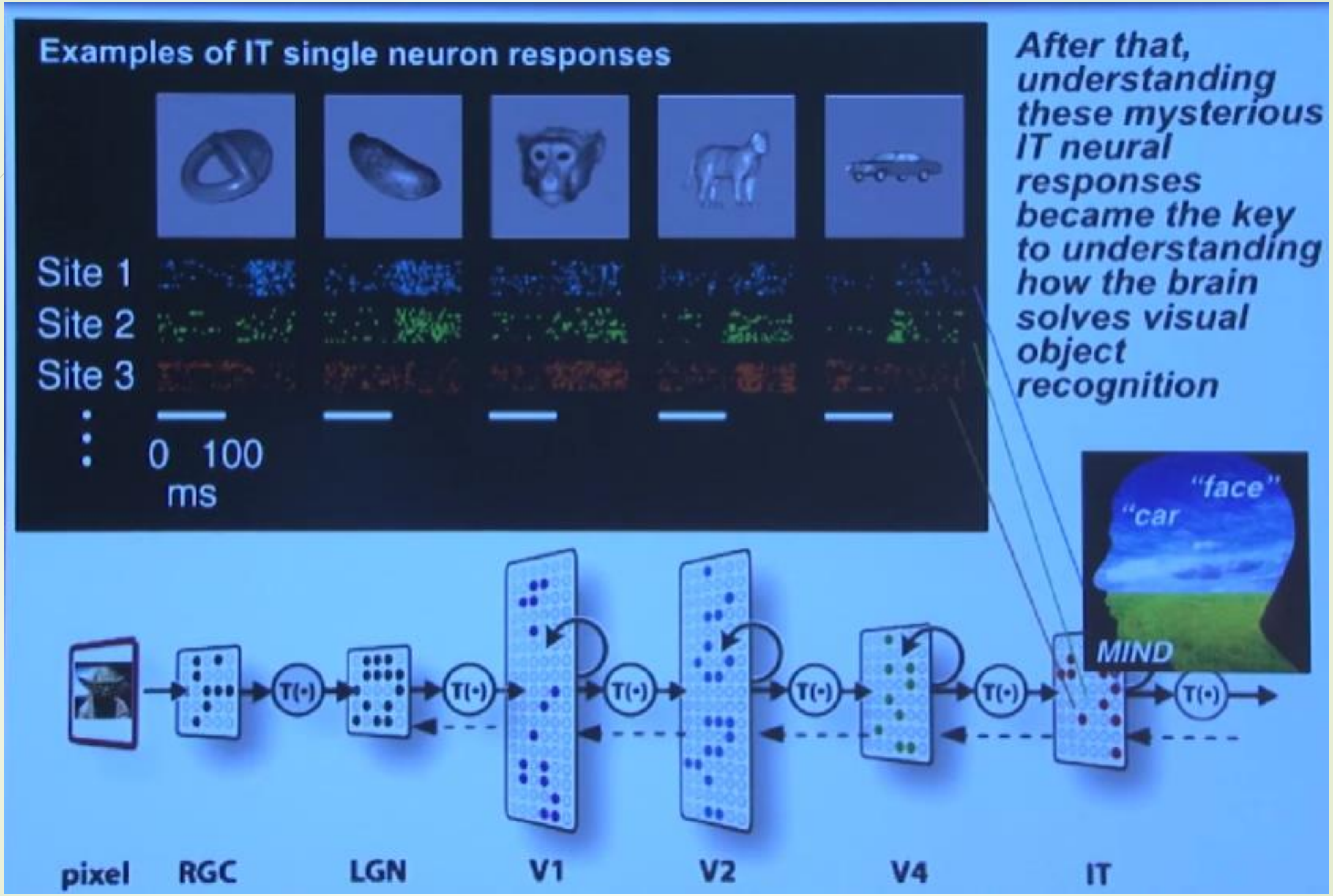

Decision to get constraint data from non-human primates
Human
Rhesus monkey
Camel
Dog
Rhino
Elephant
Wrench
Knife
Hanger
Fork
Guitar
Pen
Tank
Truck
Bird
Hammer
Gun
Table
Calculator
Spider
Leg
human behavior = non-human primate behavior
(at least for core object categorization)
Comparison of Object Recognition Behavior in Human and Monkey
R. Rajalingham, K Schmidt, J.J. DiCarlo, Vision Sciences Society (2014)
R. Rajalingham, K Schmidt, J.J. DiCarlo, J. Neuroscience (2015)

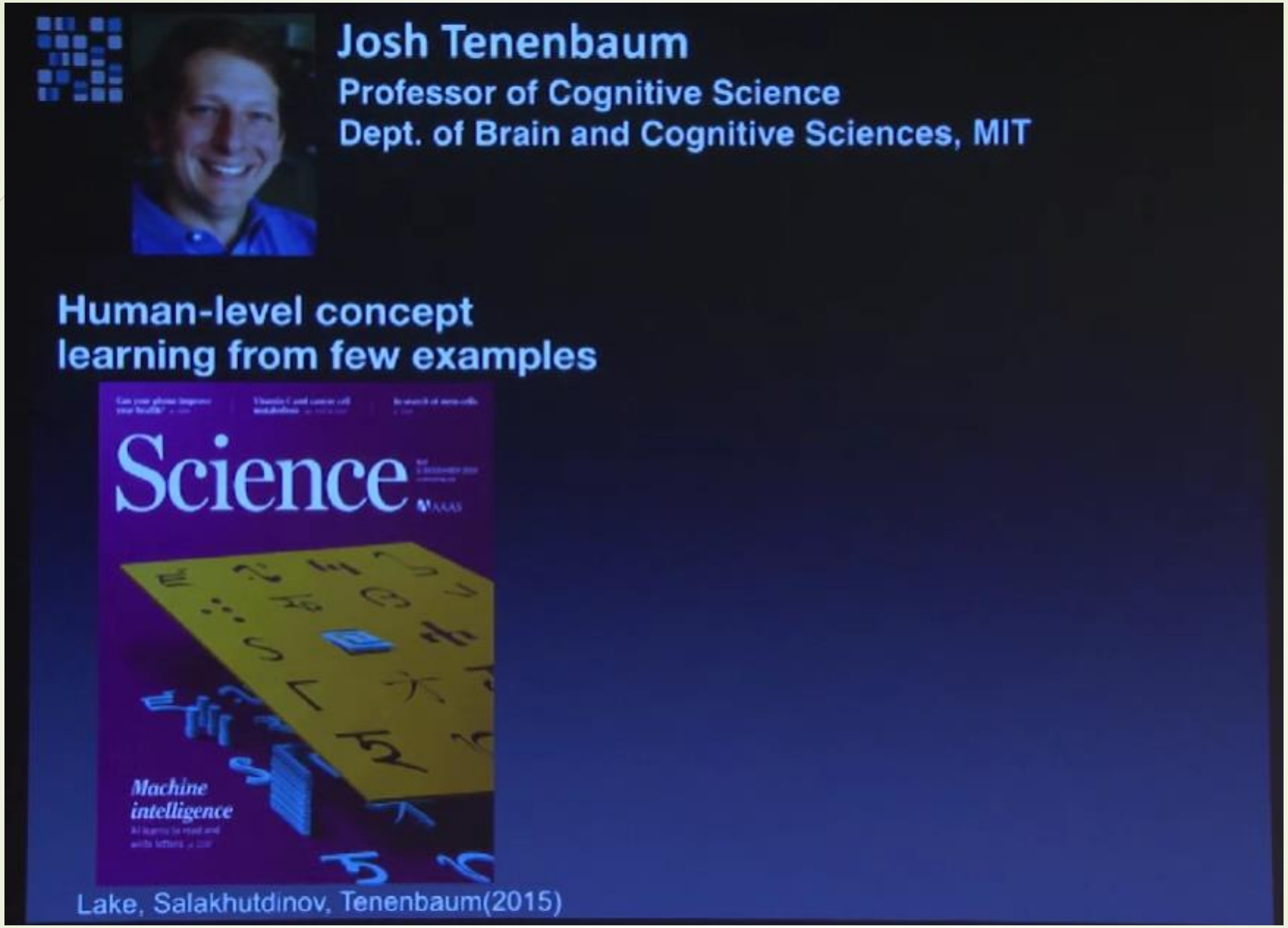


retinal ganglion cells lateral geniculate nucleus inferior temporal

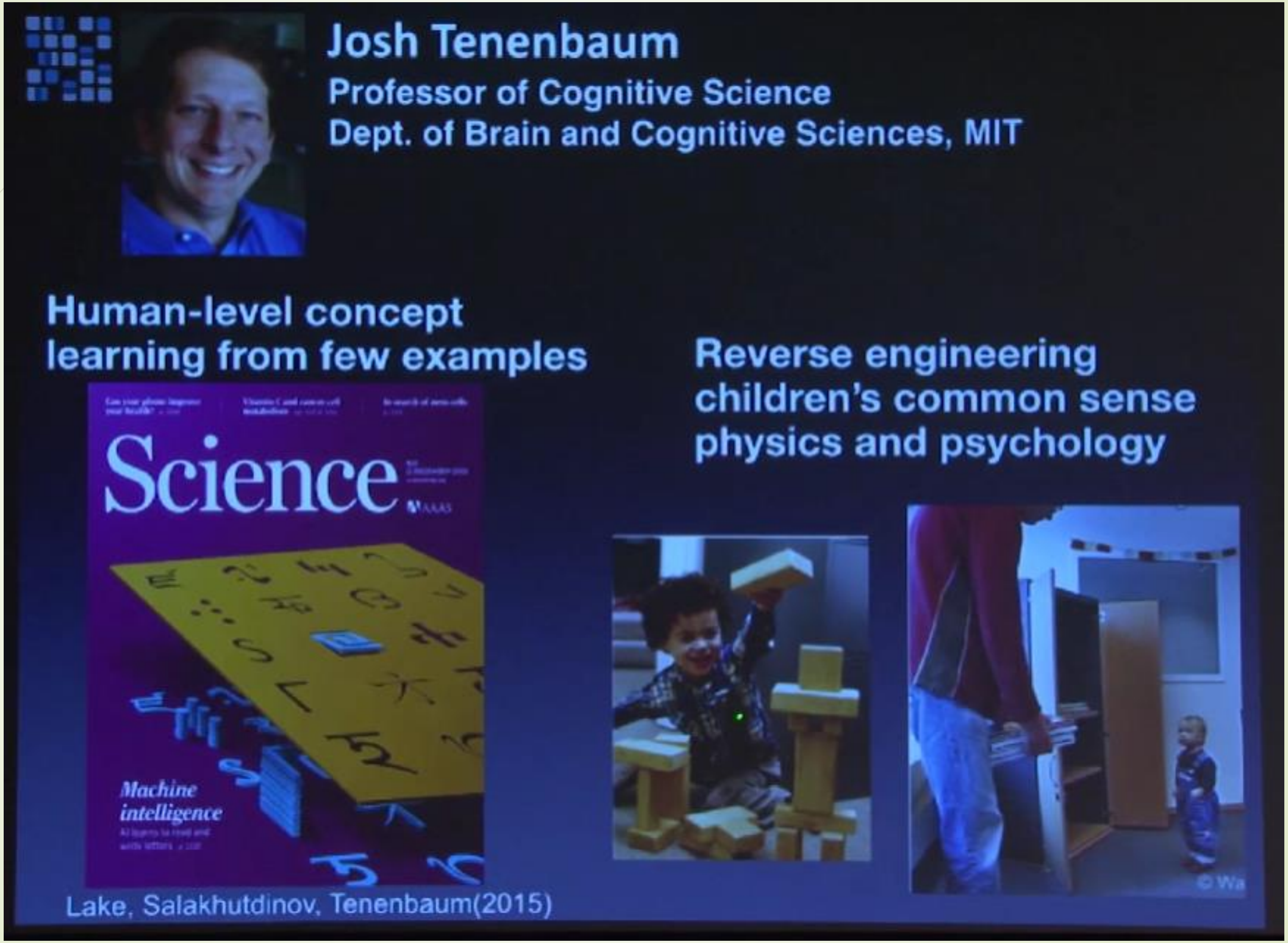


Its not photograph, its new pattern of neural activities that is evoked by an image.


Examples of IT single neuron responses
Site 1
Site 2
Site 3
0 100
ms
After that, understanding these mysterious IT neural responses became the key to understanding how the brain solves visual object recognition
"face"
"car
MIND
T(•)
pixel
RGC
LGN
V1
V2
V4
IT

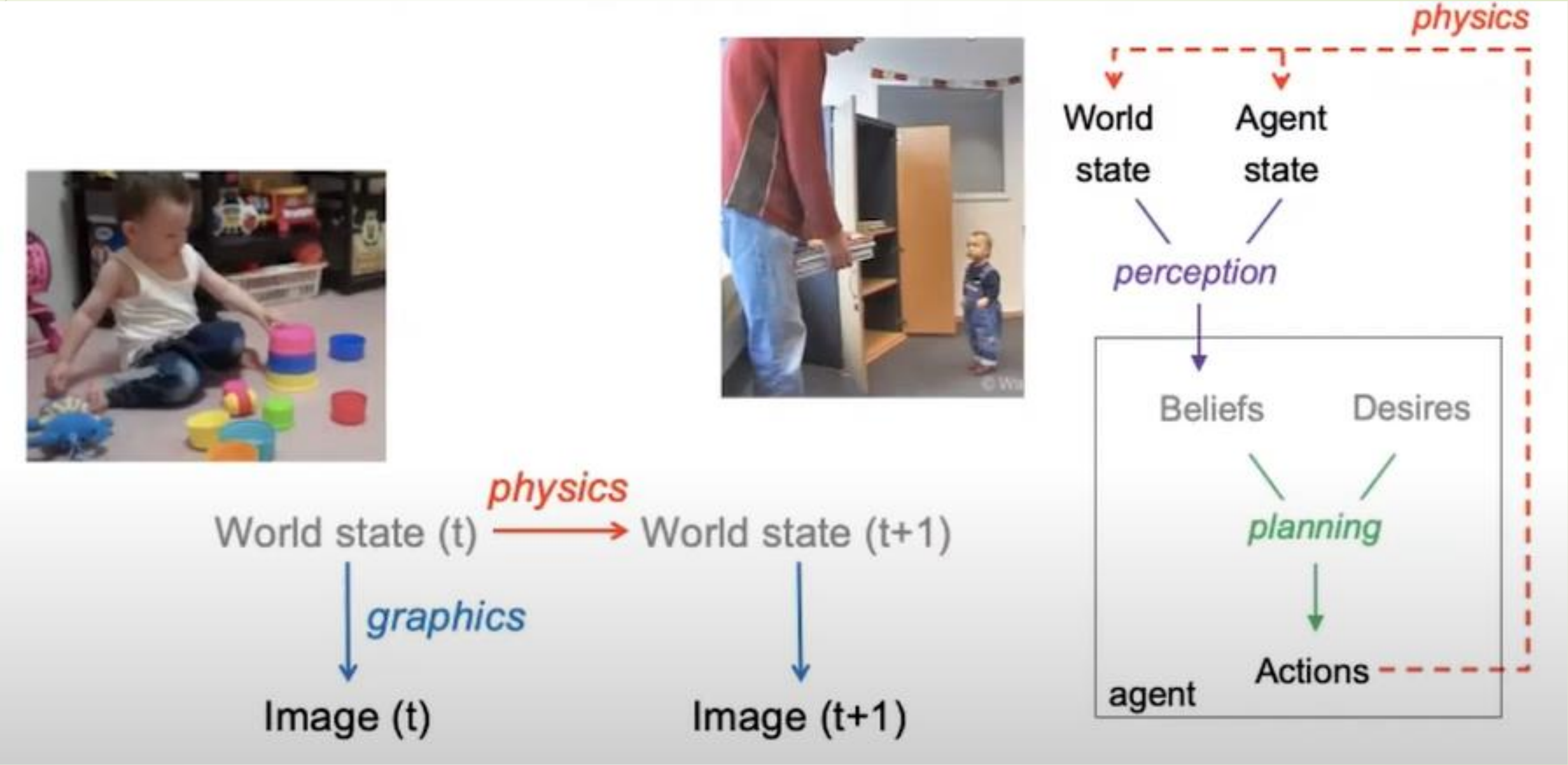


- They built a system that learn from just a few examples


Josh Tenenbaum
Professor of Cognitive Science
Dept. of Brain and Cognitive Sciences, MIT
Human-level concept
learning from few examples
Science
Machine intelligence
Reverse engineering
children's common sense
physics and psychology
Lake, Salakhutdinov, Tenenbaum(2015)

Reverse-engineering: Core Cognition

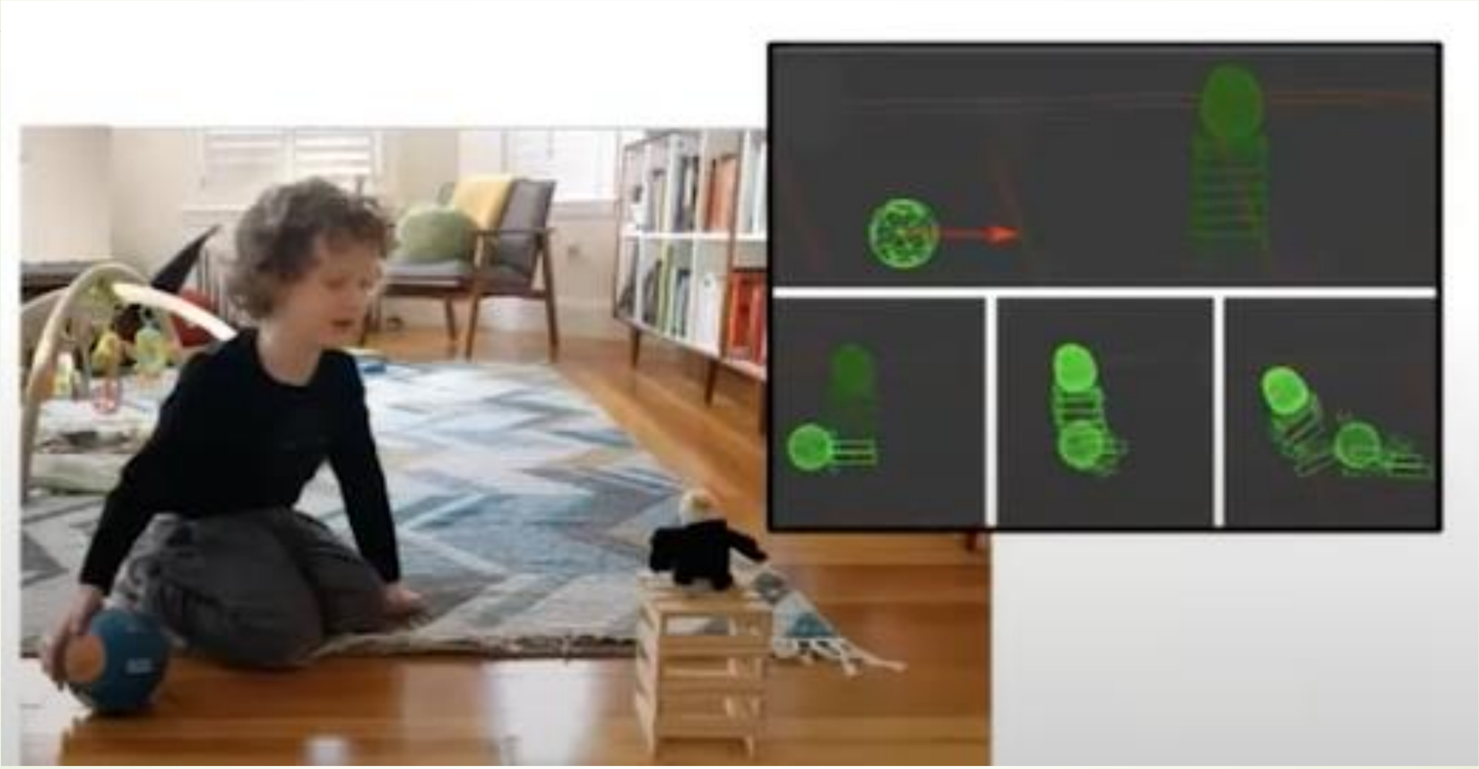
Reverse-engineering: Core Cognition



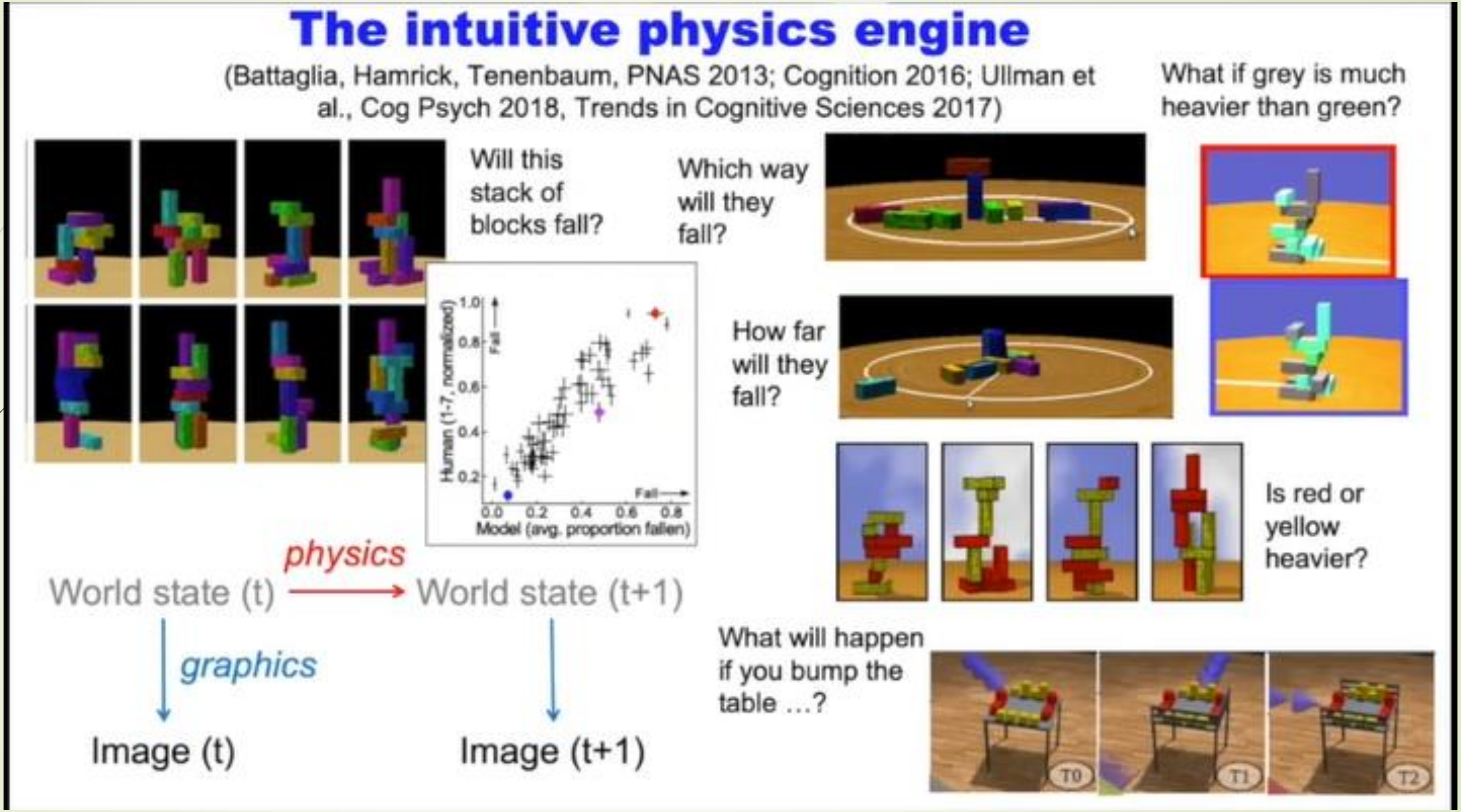
How to build this architecture?

- Probabilistic program integrate our best ideas on intelligence, across different eras of AI:
- **Symbolic Manipulations :** for representing and reasoning with knowledge base
- **Bayesian Inference :** for reasoning of unobserved causes from uncertain data
- **Neural Network :** for pattern recognition and function appx.

How to build this architecture?



Game engine in our head:
Very fast program to simulate graphics, physics and planning


The intuitive physics engine
(Battaglia, Hamrick, Tenenbaum, PNAS 2013; Cognition 2016; Ullman et al., Cog Psych 2018, Trends in Cognitive Sciences 2017)
What if grey is much heavier than green?
Will this stack of blocks fall?
Which way will they fall?
How far will they fall?
Human (1-7, normalized)
Model (avg. proportion fallen)
Fall
Is red or yellow heavier?
physics
World state (t)
World state (t+1)
graphics
Image (t)
Image (t+1)
What will happen if you bump the table …?
T0
T1
T2