Methods in AI Research
Cognitive Processing 1: Modeling human behavior

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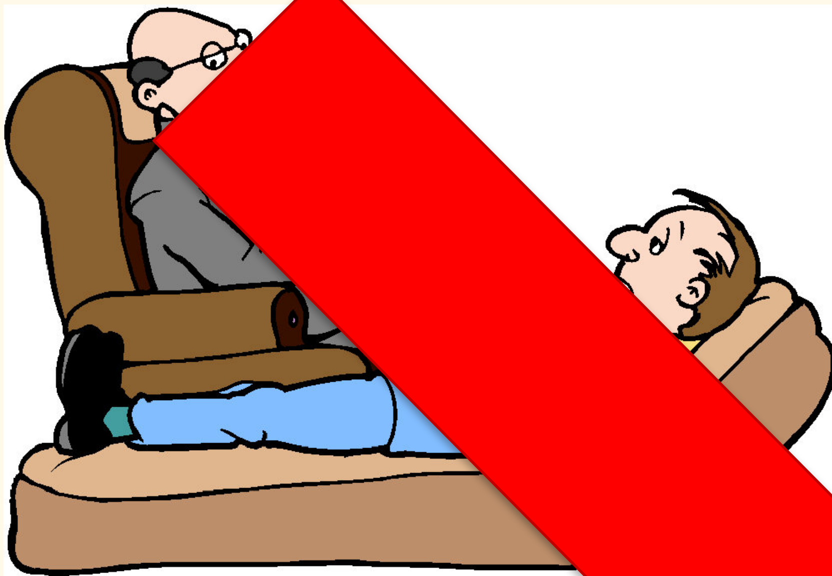


In spirit of Dartmouth workshop

“The study is to proceed on the basis of
the conjecture that every aspect of
learning or any other feature of intelligence
can in principle be so precisely described that
a ***machine can*** be made to ***simulate*** it.”

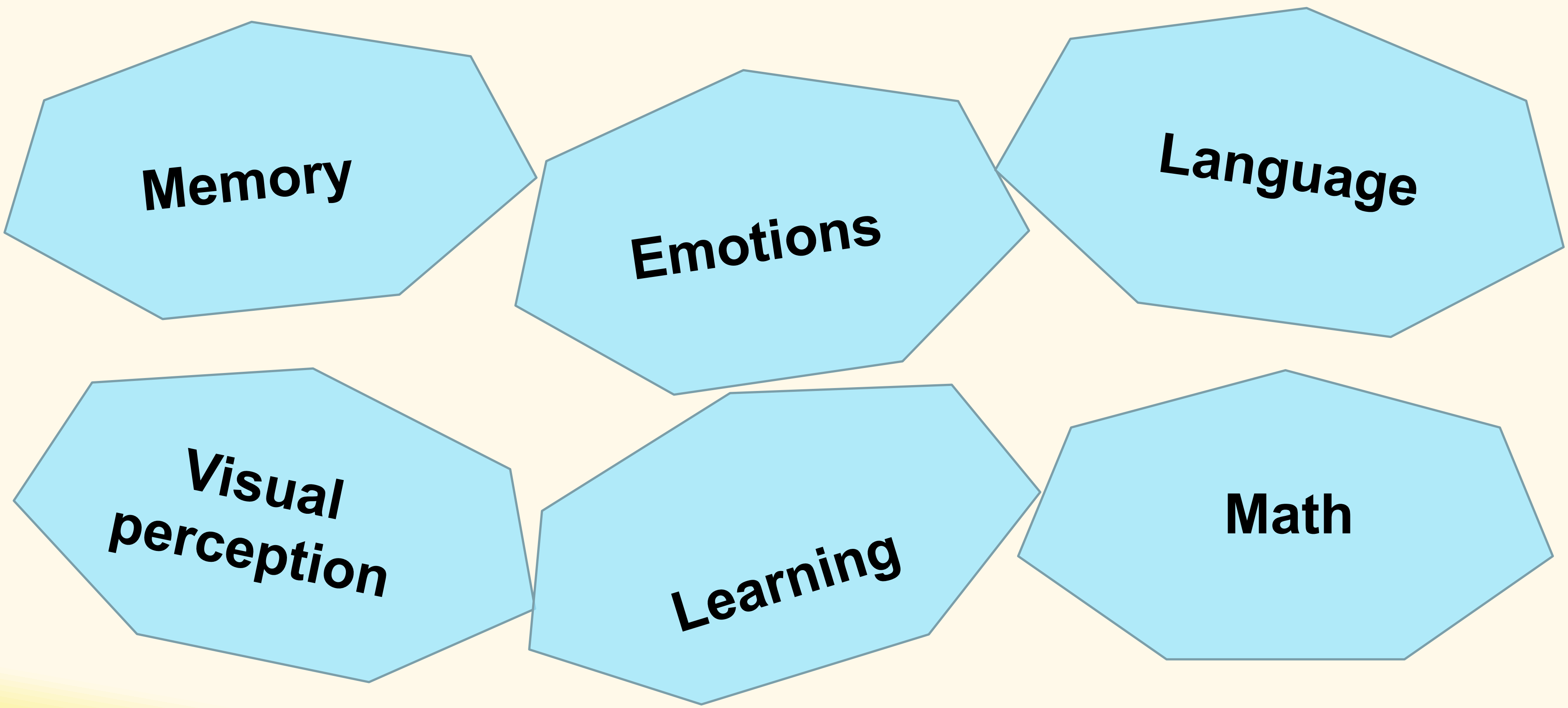
Some topics:

- ✓ Language processing & -production
- ✓ Neural nets (cognitive modeling)
- ✓ Abstraction (from sensor data to concepts)
- ✓ Creativity

Today’s topics

- Why use models?
  - In science
  - In practice / industry
- What is a cognitive architecture?
  - What are the (dis-)advantages?
  - What is contrast with cognitive model?
  - Example: multitasking in ACT-R
- What makes a good model?
  - Level of abstraction
- If you want to know more…

Psychology: Diverse field

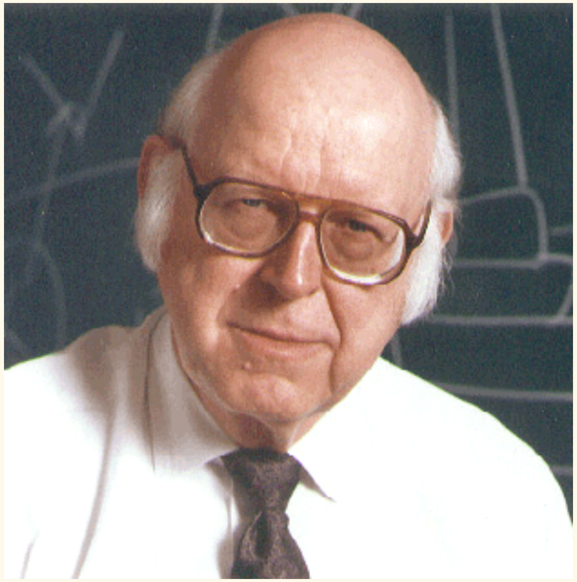


Physics: Converging field

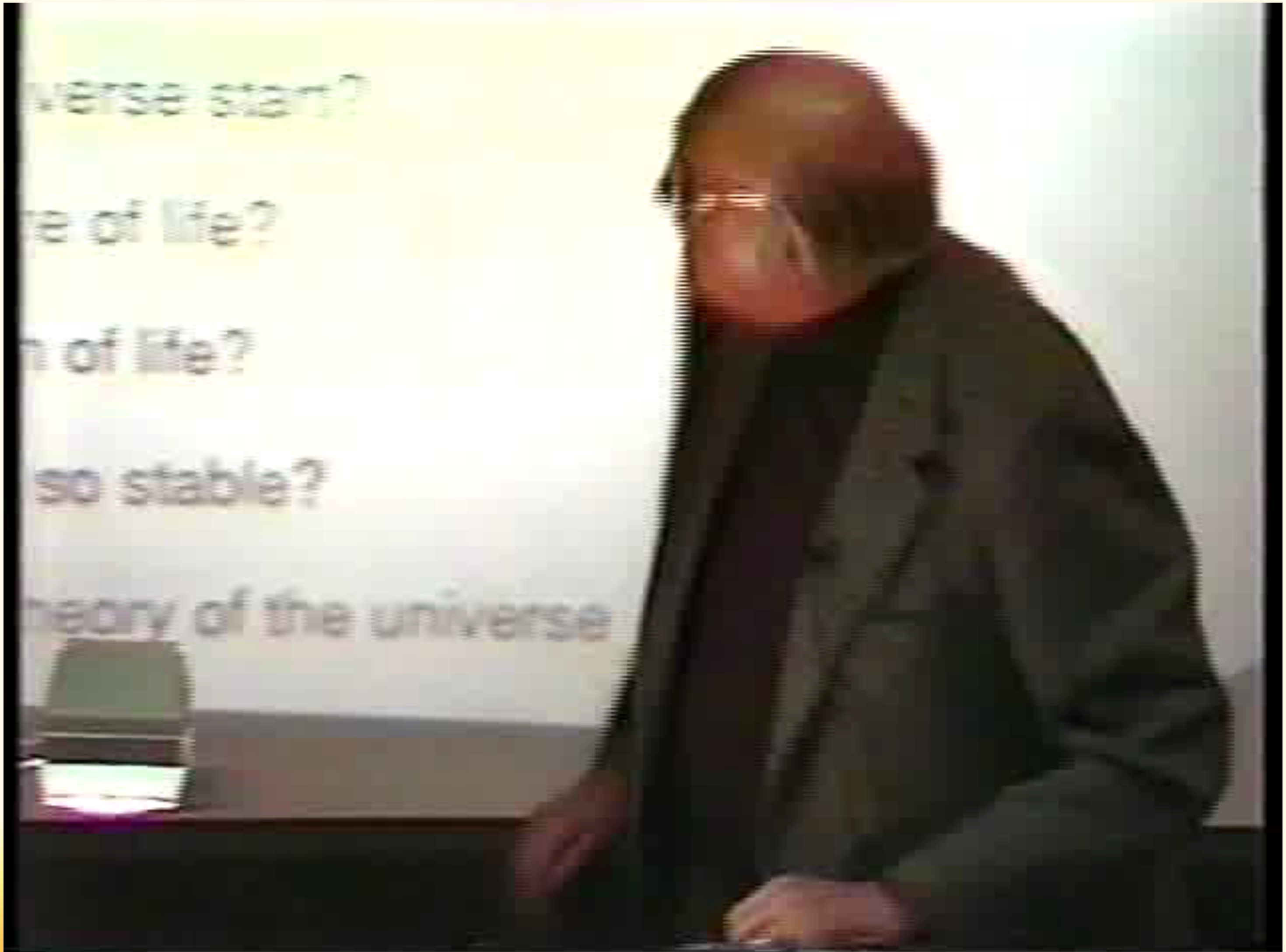
Core idea of Cognitive Modeling (& AI)

- ‘Make psychology more like physics’
- How can the mind occur in the physical universe?

➔Unified Theory of Cognition
(Allen Newell, 1990)



http://act-r.psy.cmu.edu/misc/newellclip.mpg

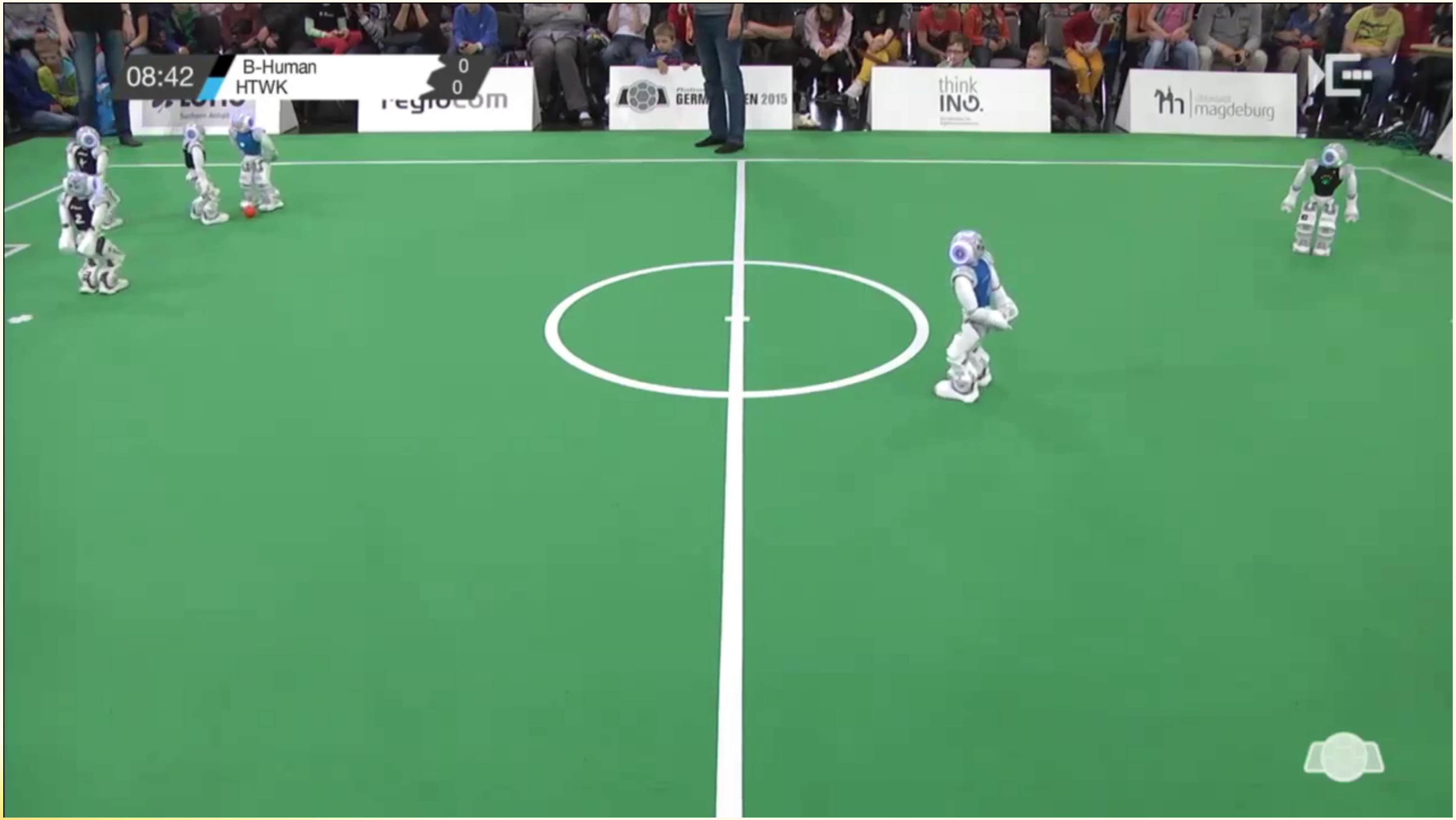


Why use computer models/simulations?

1. *Formal* specification of a theory: working code
2. Working code is *detailed*
   – Allows for scrutiny & scientific discussion
3. Model can make *predictions*
4. Understanding by *building*

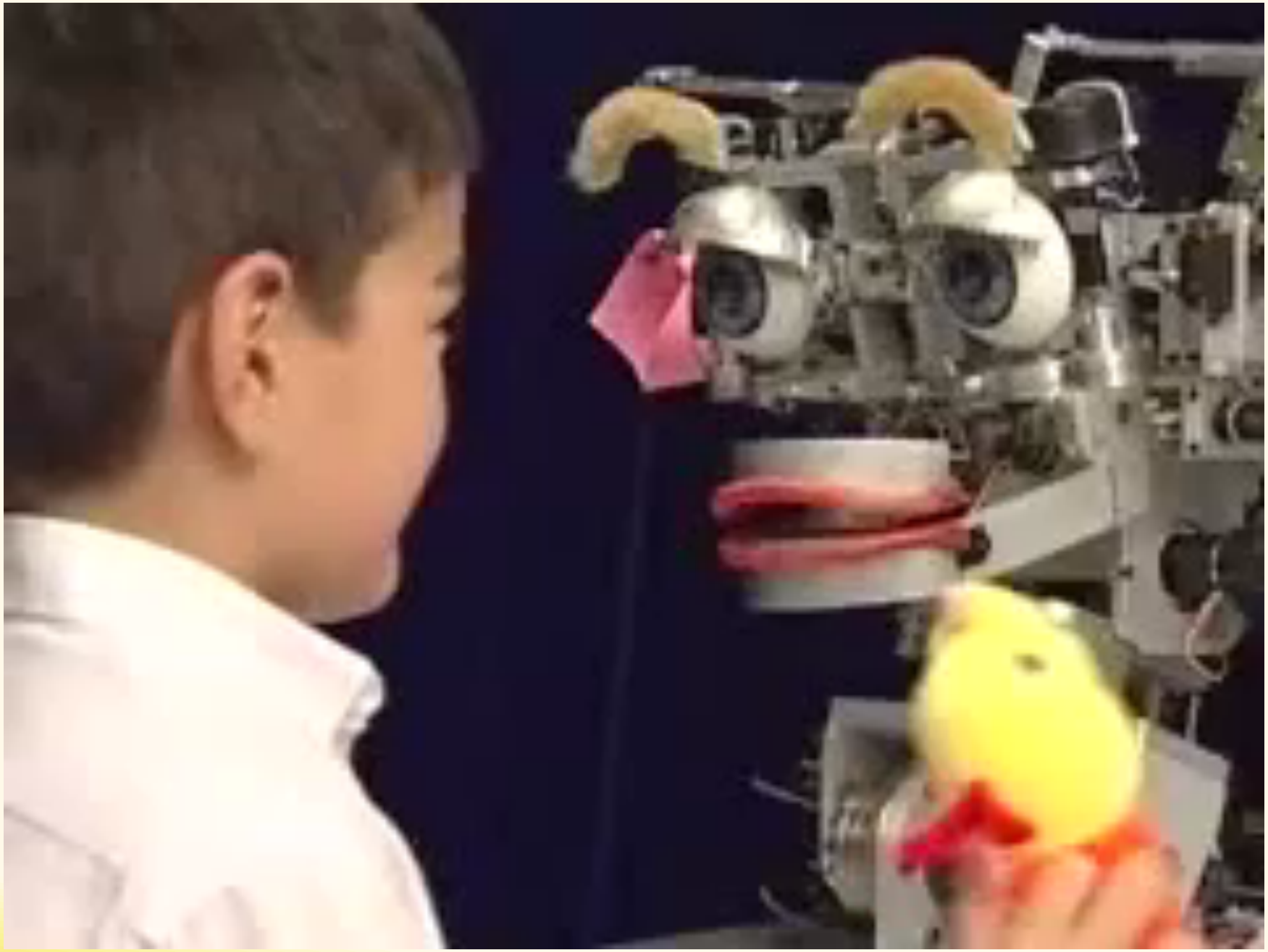
- Like physics:
  – Describe nature using equations
  – Apply equations to dataset / situation

Understanding by building



Robocup Standard League Finals 2014

Understanding by building



MIT’s Kismet

Understanding by building

See: http://cog.cs.drexel.edu/distract-r/

Why use computer models/simulations?

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4. Underst *uilding*

Scientific motivation

• physics:
   – Describe nature using equations
   – Apply equations to dataset / situation

Why use models in practice/industry?

- Intelligent tutor systems
- Intelligent game opponents
- Usability test
- Adaptive interface: interruptions

➔ ***Applied systems informed by theory***

Intelligent tutor systems

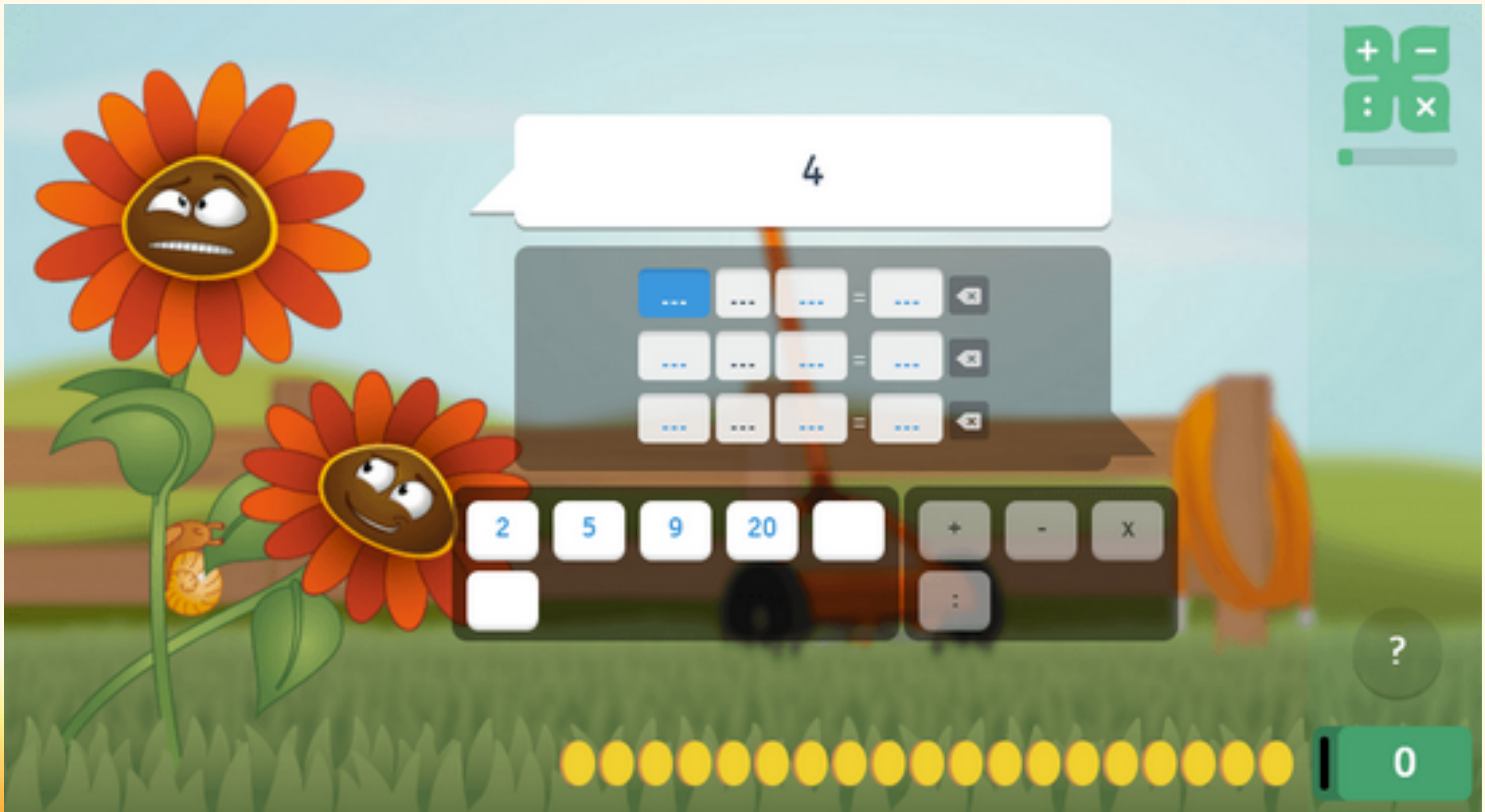
- $2X + 7 = 27$

  $X = ?$
- Answer student: $x = 17$

- Questions a tutor system addresses:
  - What went wrong?
  - What to practice next?
  - What instructions should be given?

Intelligent tutor systems: State of the art

- www.rekentuin.nl >1600 schools



Intelligent tutor systems: State of the art

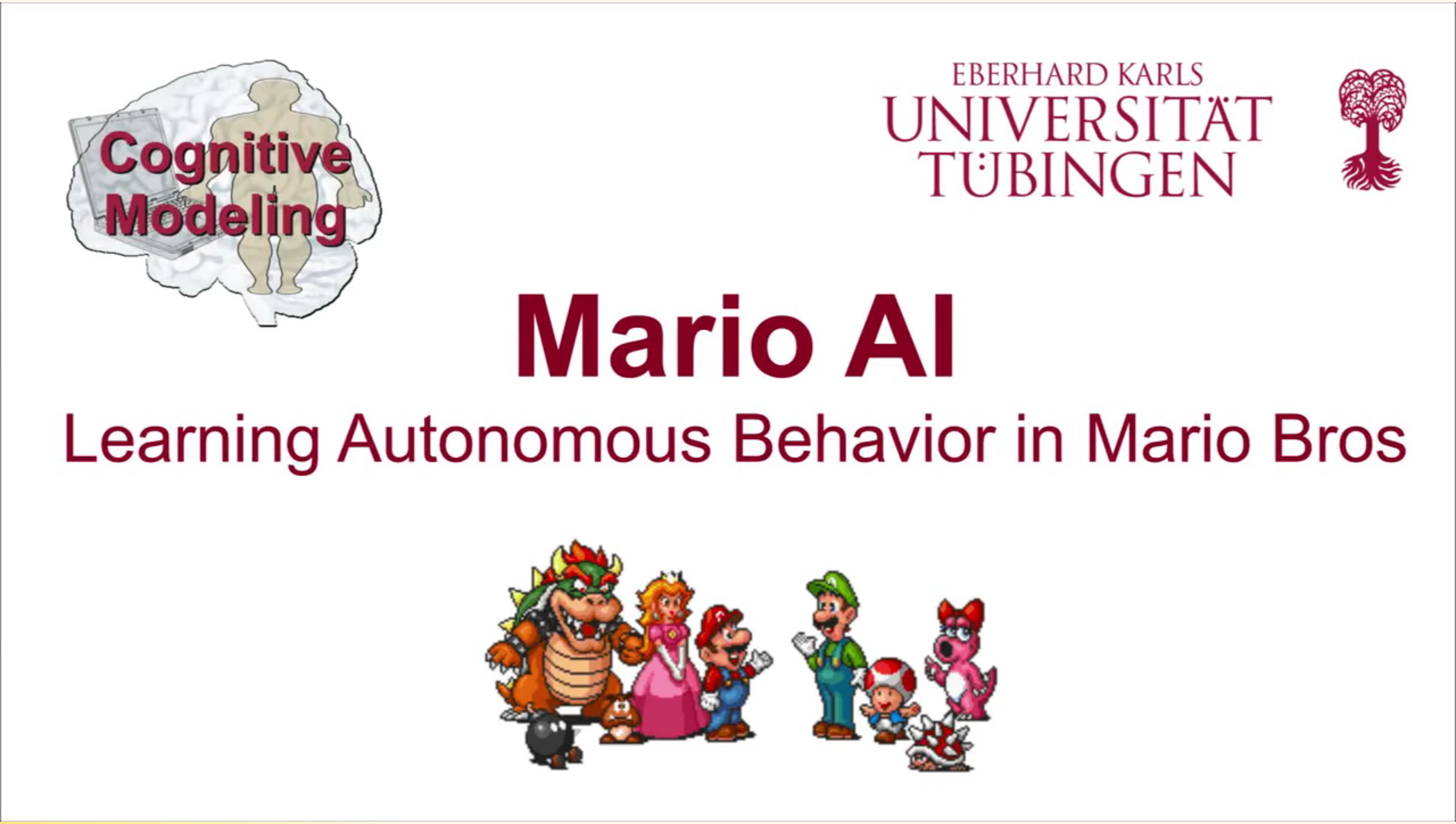
Anderson, J. R., Betts, S., Ferris, J. L., & Fincham, J. M. (2012). Tracking children's mental states while solving algebra equations. *Human brain mapping*, *33*(11), 2650-2665.

For video see: http://act-r.psy.cmu.edu/wordpress/wp-content/uploads/2013/09/kidalg_mix_ascaled_text1.mp4

Intelligent game opponents

“Beating the human” – not our goal

Intelligent game opponents: State of the art



https://www.youtube.com/watch?v=ApIG6KnOr2Q

Intelligent game opponents: State of the art

https://www.youtube.com/watch?v=FAU2I4ZgDsw

Siebert, Gray, Lindstedt (2017) Topics in Cognitive SCience

Intelligent game opponents: State of the art

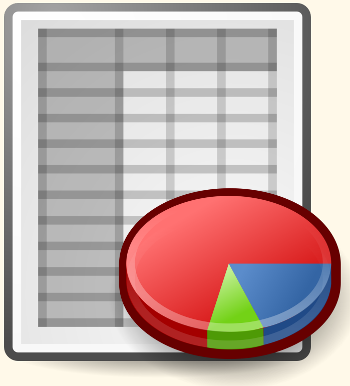
Sangster, Gray (2017) MathPsych; Sangster, Medonca, Gray (2016) Human Factors conference

Usability Test: Distract-R

See: http://cog.cs.drexel.edu/distract-r/

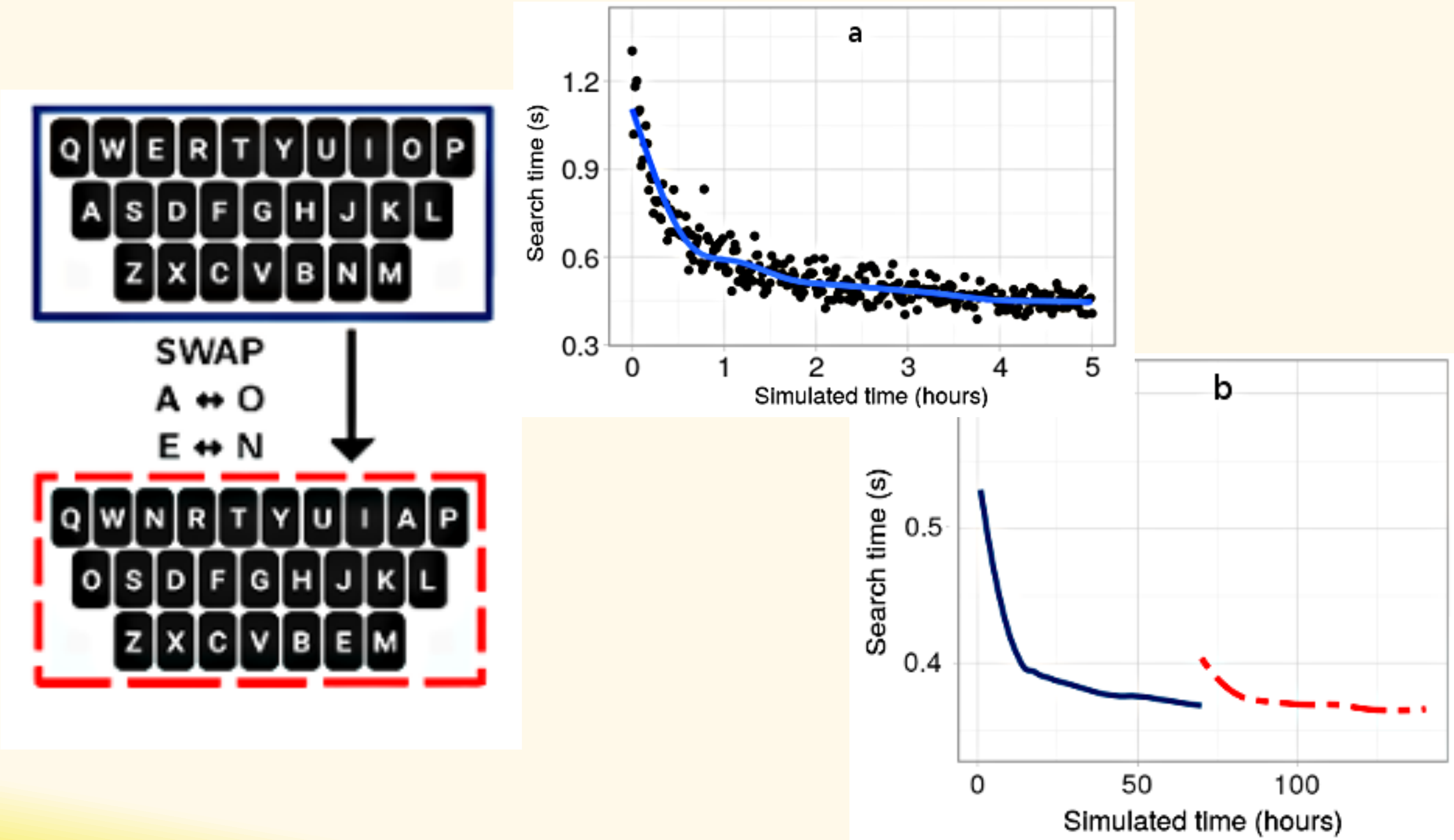
Adaptive interface: interruptions

facebook



Iqbal, S. T., & Bailey, B. P. (2010). Oasis: A framework for linking notification delivery to the perceptual structure of goal-directed tasks. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *17*(4), 15:1–28.

Software & interface (re-) design



https://users.aalto.fi/~jokinej10/visual-search/

Jokinen et al (2017; CHI)

Why user models for practice?

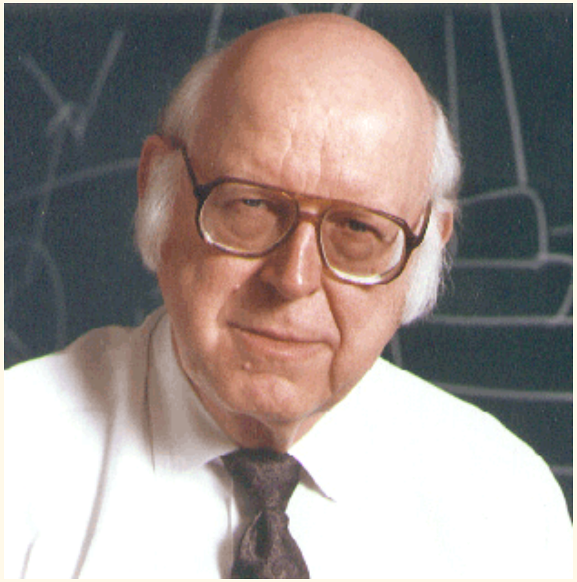
1. Have human-like experiences
   – Game opponent -> requires understanding first
2. Make appropriate, (adaptive) decisions due to understanding of user:
   – Feedback (tutor)
   – Difficulty (game)
   – Usability
   – Adaptive interface (interruptions)
   – Software & interface (re-) design

Today’s topics

- Why use models?
  - In science
  - In practice / industry
- What is a cognitive architecture?
  - What are the (dis-)advantages?
  - What is contrast with cognitive model?
  - Example: multitasking in ACT-R
- What makes a good model?
  - Level of abstraction
- If you want to know more…

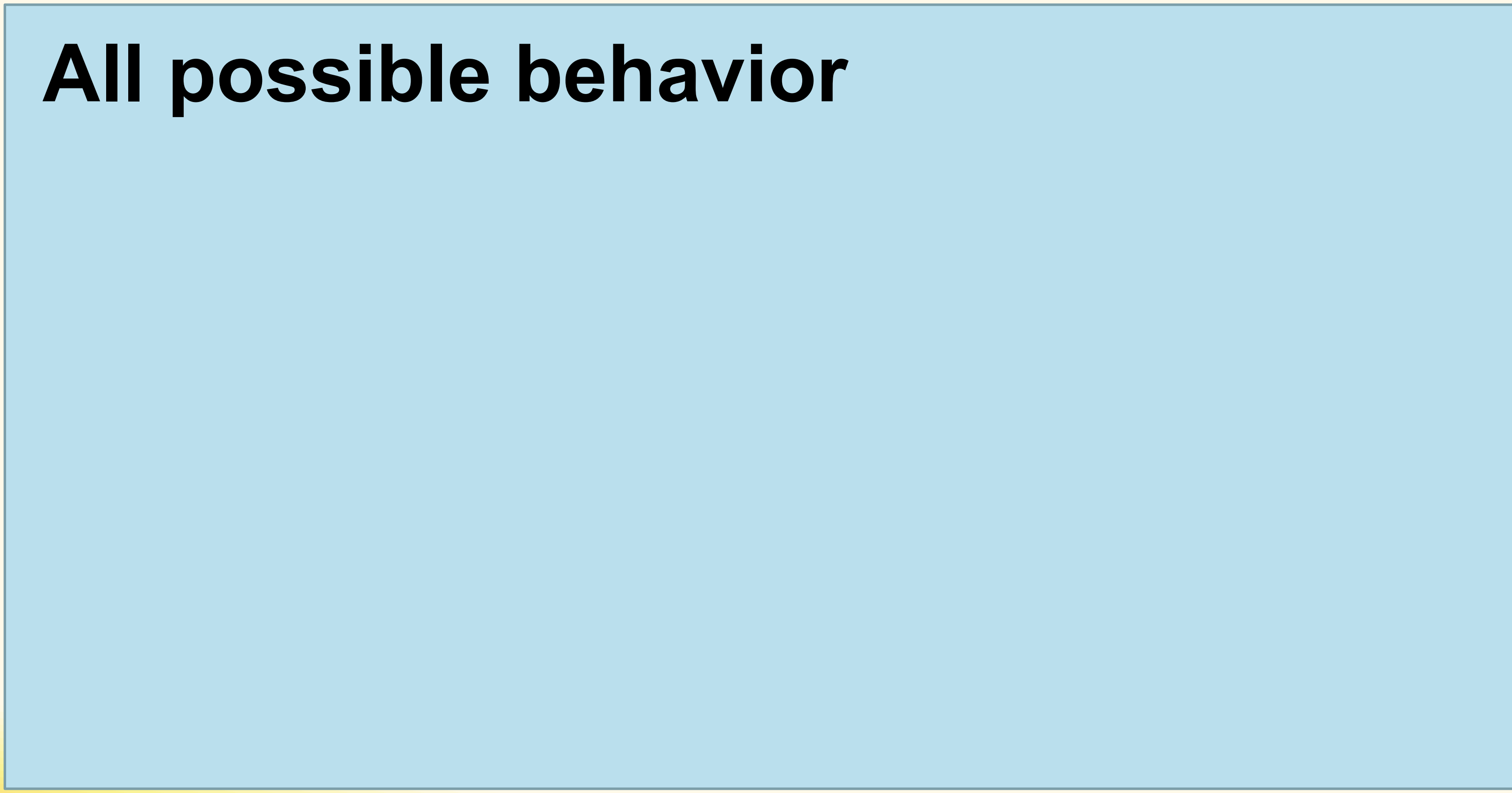
More about the basic science…

➔Unified Theory of Cognition (Allen Newell, 1990)



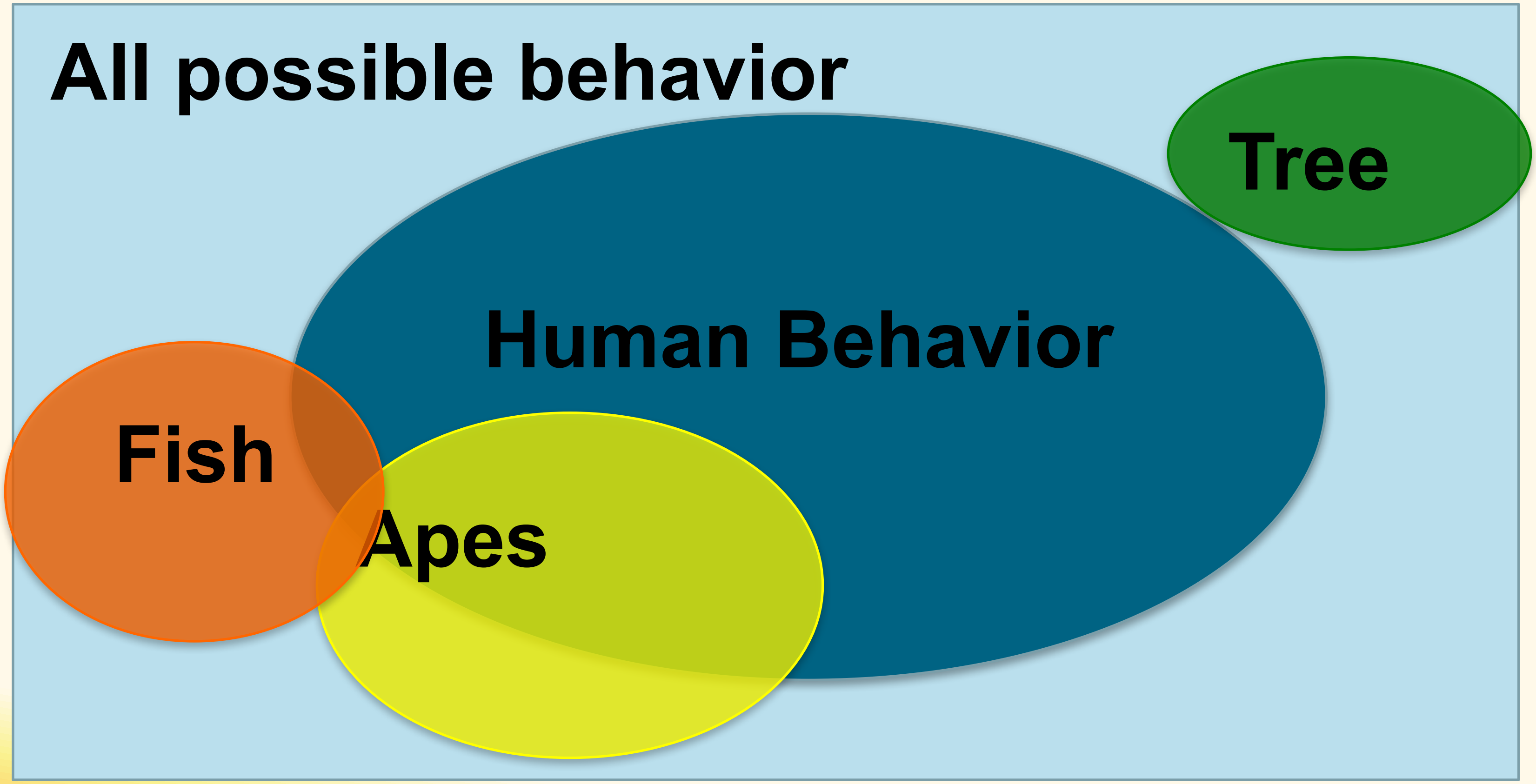
Unified Theory of Cognition

illustration with Venn Diagrams



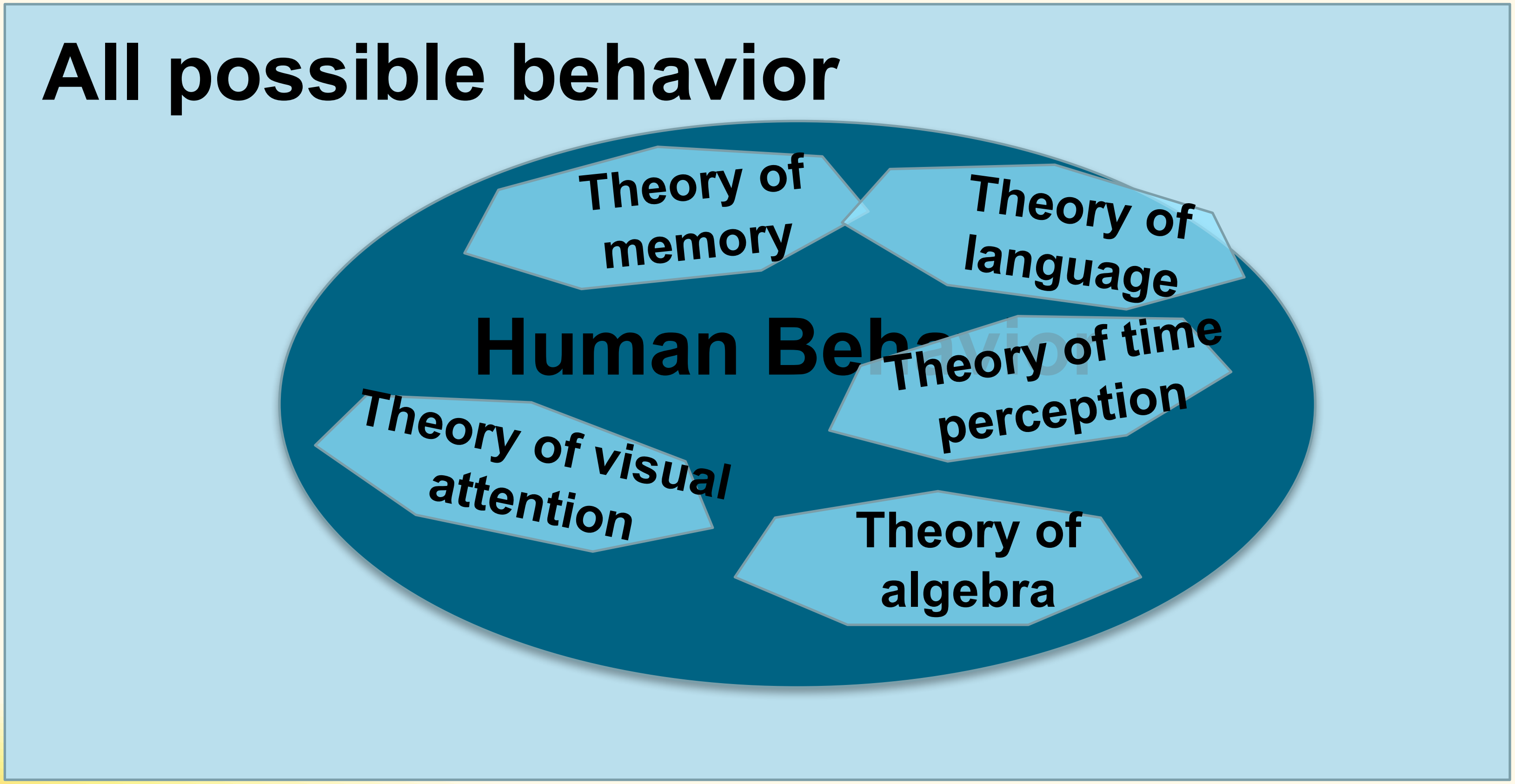
Unified Theory of Cognition

illustration with Venn Diagrams



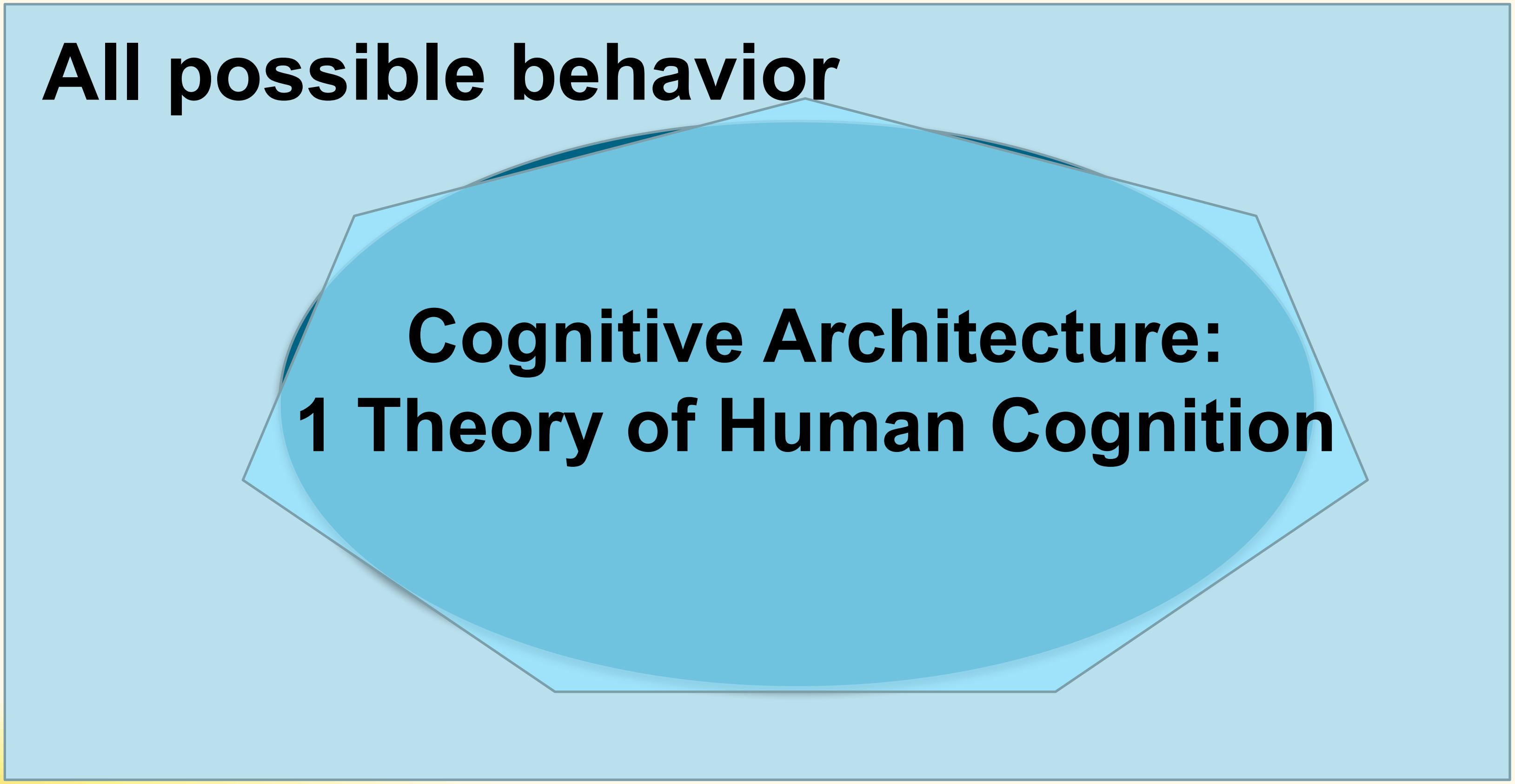
Unified Theory of Cognition

illustration with Venn Diagrams



Unified Theory of Cognition

illustration with Venn Diagrams



Unified Theory of Cognition

- **Newell's goal:**
  - **Develop 1 theory that can describe (almost) all facets of human behavior**
  - **Describe interactions between theories of different domains/situations/components**

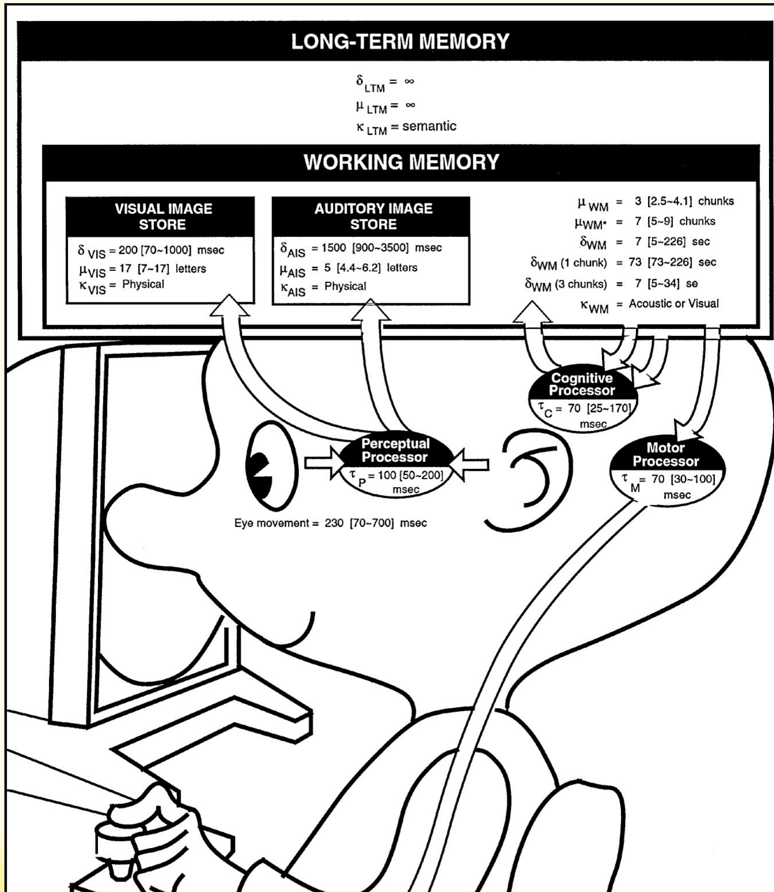
- ***Cognitive Architecture*** **(Bell & Newell, 1971)**
  - **Within the architecture you develop models of specific tasks/settings**

Example of Cognitive Model in Architecture

Cognitive Architecture & Cognitive Model

- **Cognitive *Architecture* (John Anderson, 2007)*:***
  "a specification of the <u>structure</u> of the <u>brain</u> at the level of abstraction that explains how it achieves the <u>function</u> of the mind"

- **Explains:**
  - **What brain can & can't do (function)**
  - **How it does that (structure)**
  - **What *general* parameters and equations govern behavior**



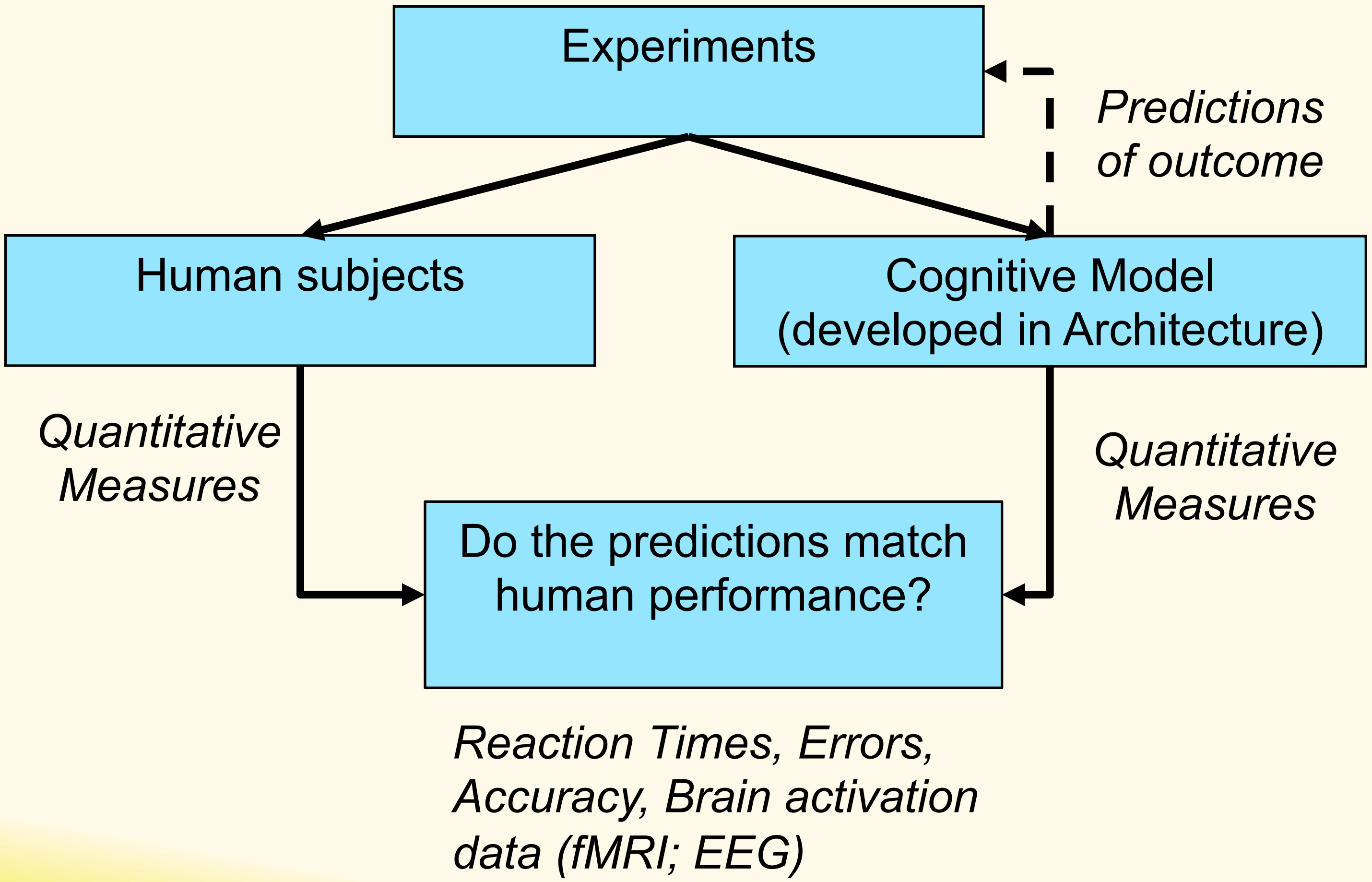
Cognitive Architecture & Cognitive Model

- Cognitive *Model*
  - A model of a *specific* task or process
  - Developed *within* or *inspired by* an architecture

Cognitive Architecture & Cognitive Model

- **Architecture questions:**
  - What is our general memory capacity?
  - How do we forget information over time in general?
  - How much visual information can we process per time unit?
  - How do we control our hands in general?
- **Model questions:**
  - How do we calculate 101 x 7 – 3 (given architecture)
  - How do we control a car (given architecture)
  - How do we divide time between driving and making a phone call (given architecture)

Testing a Model



Cognitive Architectures & Turing Machine

- **Alan Turing (1936): Turing Machines can compute all ‘computable’ functions**
  - Computer simulations can (in principle) do more than humans

- **Implication:**
  - *Constrain* the cognitive architecture
  - Do tasks in a “human way”

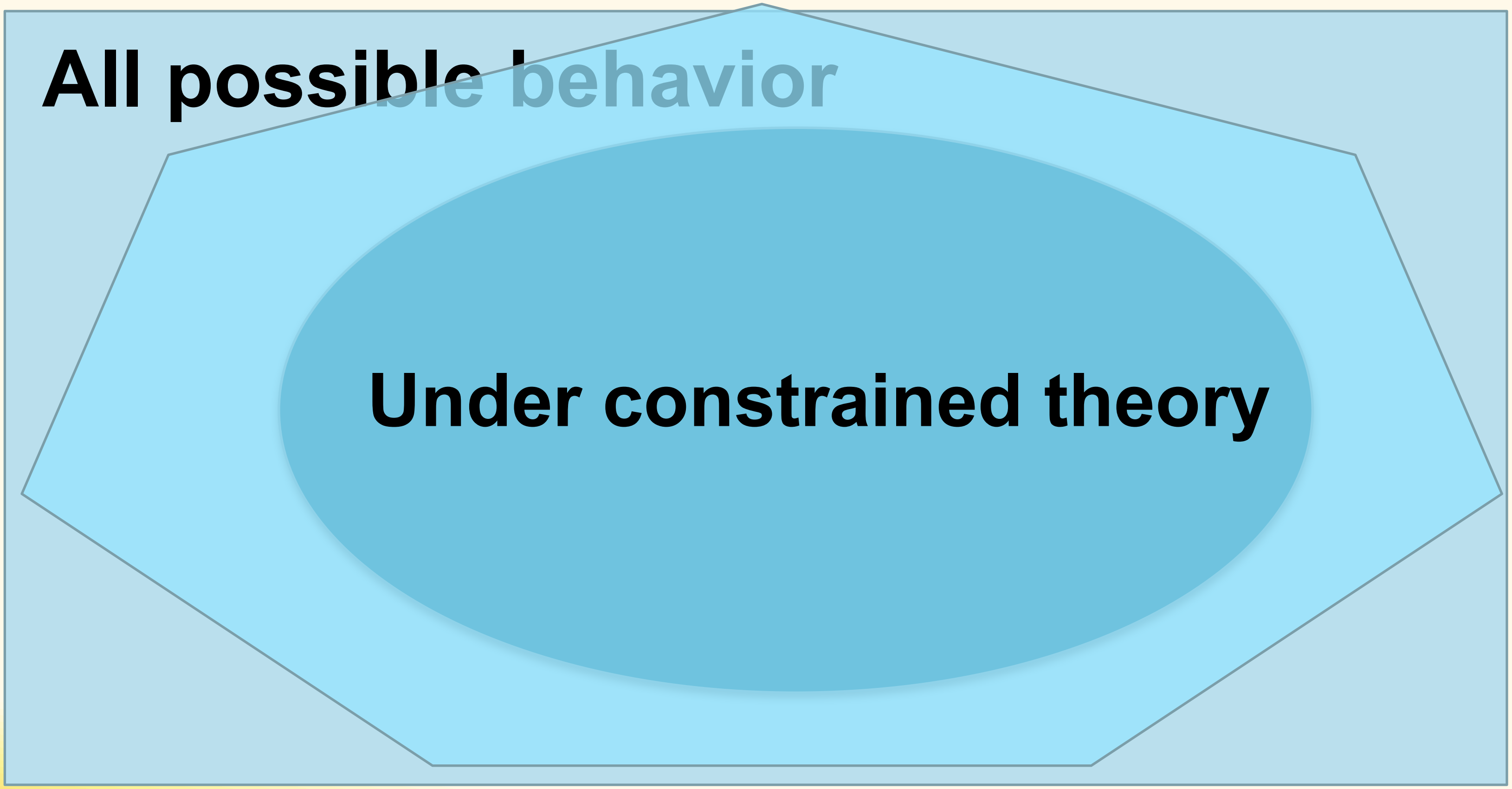
Cognitive architectures vs Turing machine

Cognitive Science style AI:
Understand human by replicating

Engineering :
Develop (more) intelligent systems

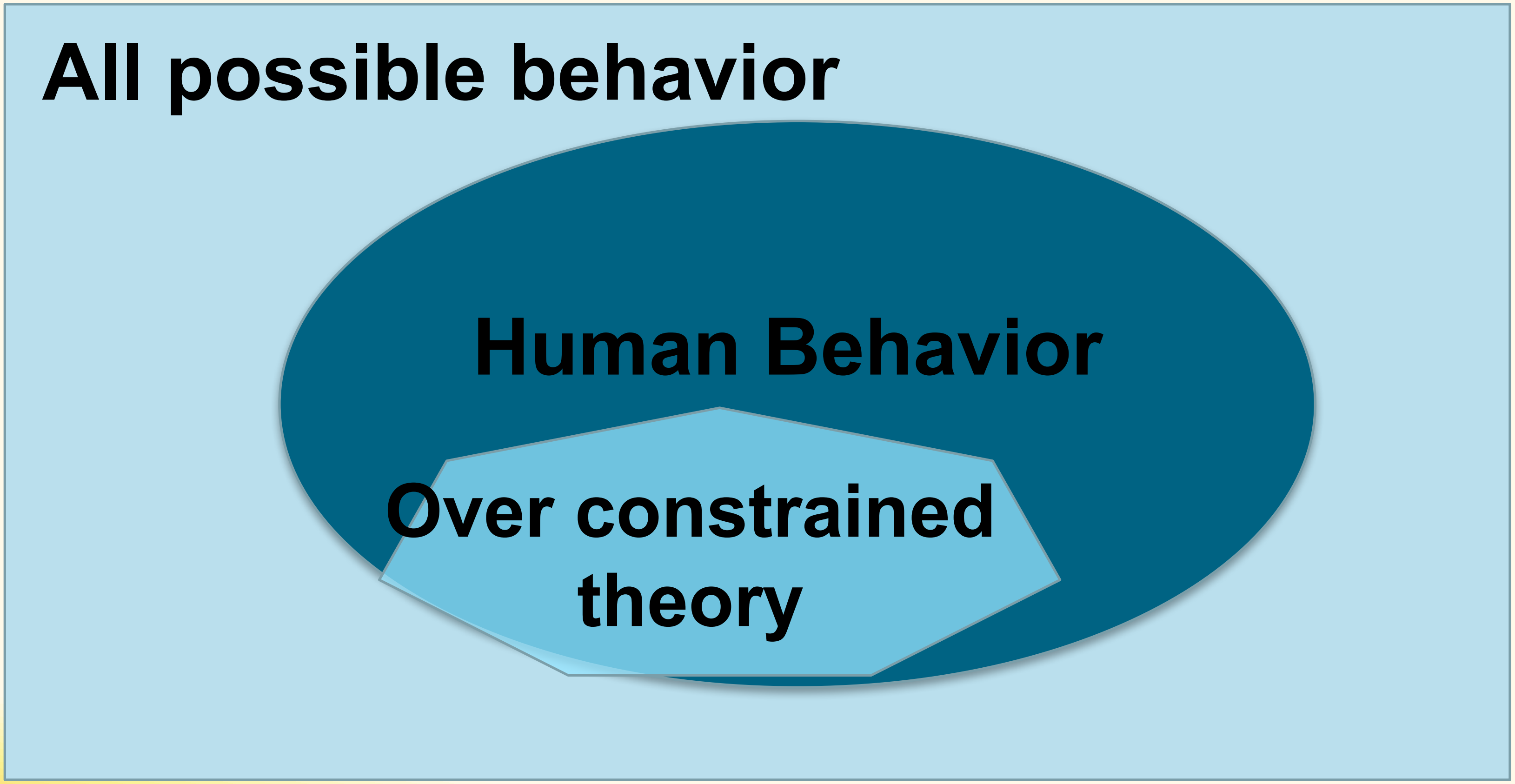
Venn diagrams – revisited

Under constrained model (Turing machine / Mr Data)



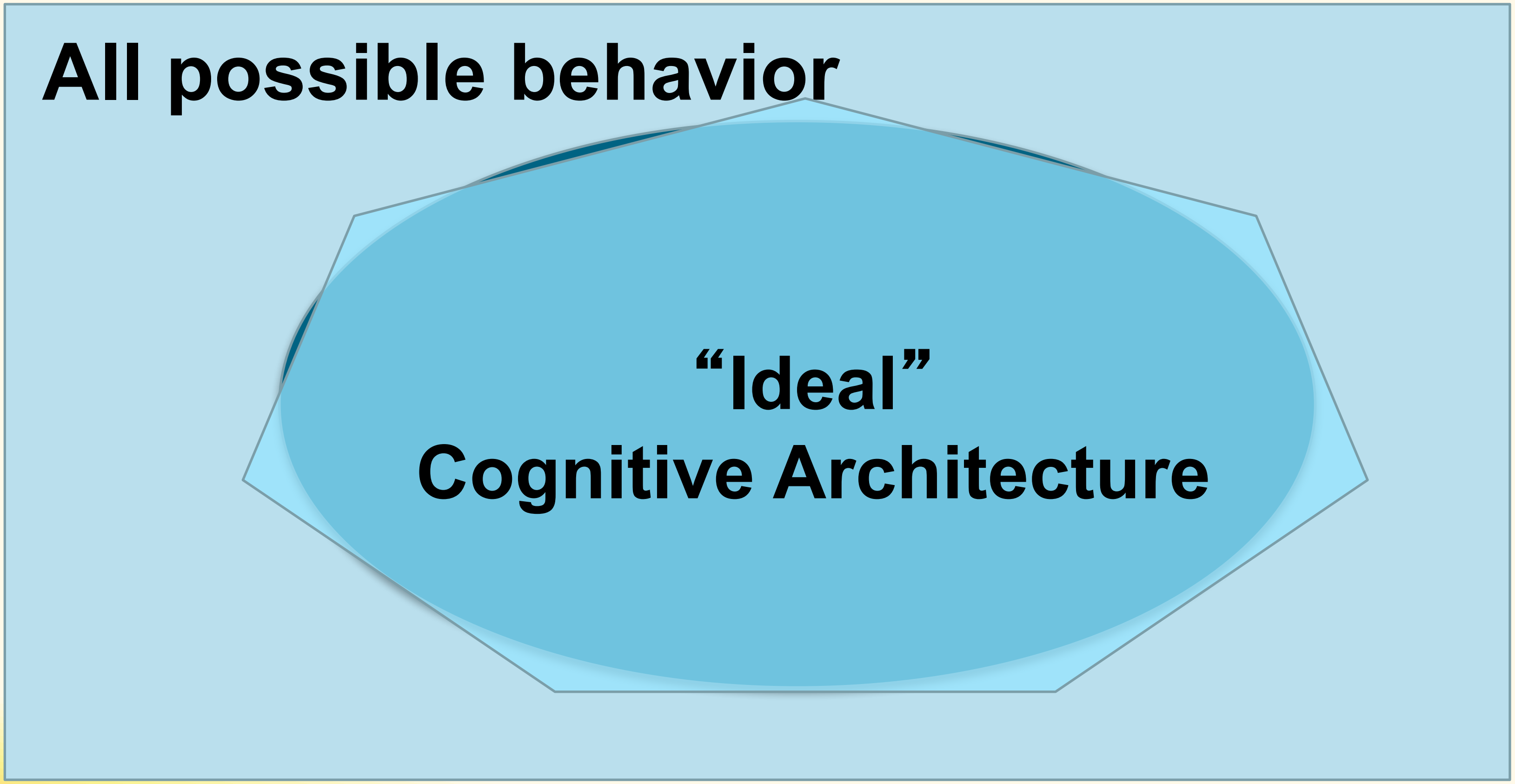
Venn diagrams – revisited

Over constrained model

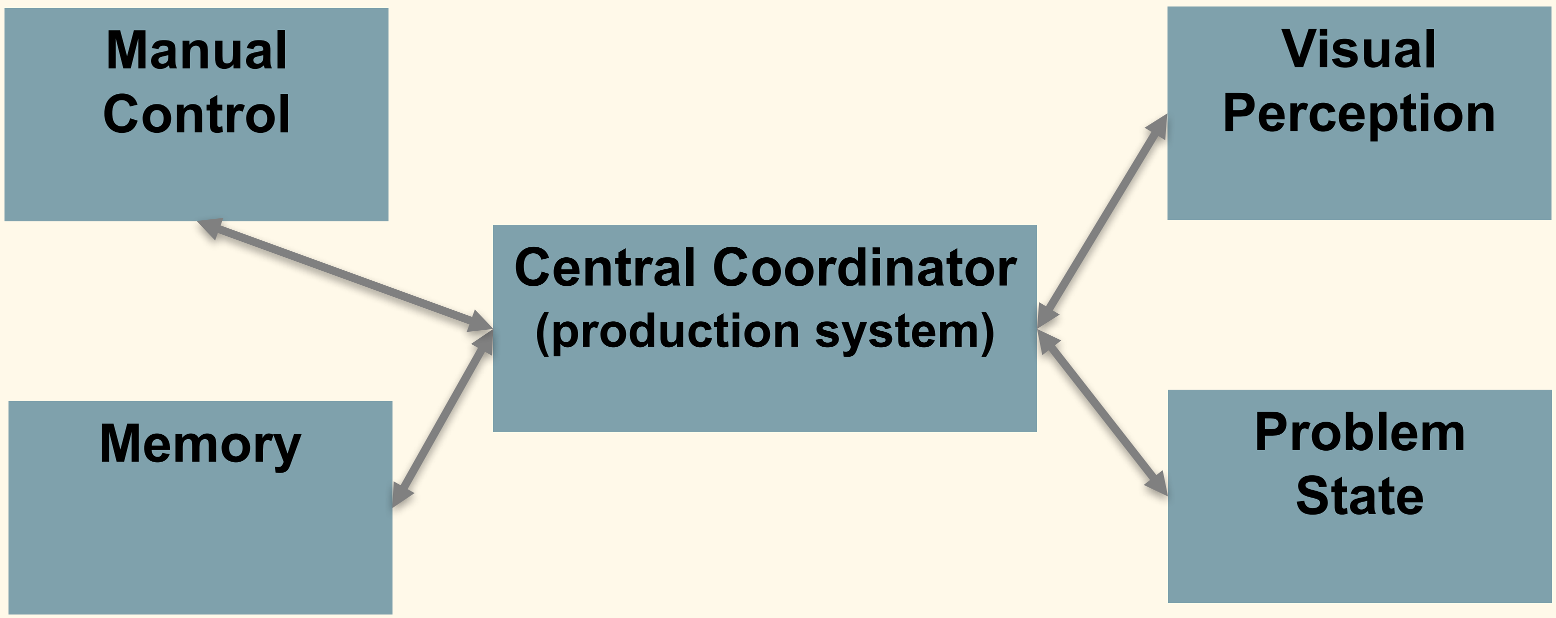


Unified Theory of Cognition

Ideal architecture



Example: Multitasking in ACT-R
(Anderson, 2007; Salvucci & Taatgen, 2011)



One model in cognitive architecture

1. Identify which functions are achieved by the brain/cognition on each time step
2. Specify each process using principles of the architecture
   - Which module executes this process & how?

(exact details left out for now)

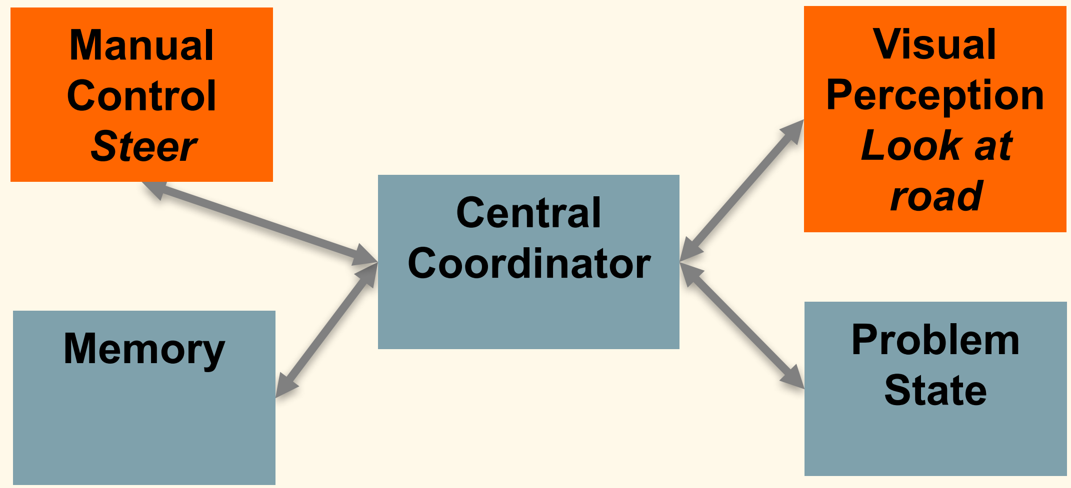
Multitasking in Cognitive Architecture
(Salvucci & Taatgen, 2008, 2011)

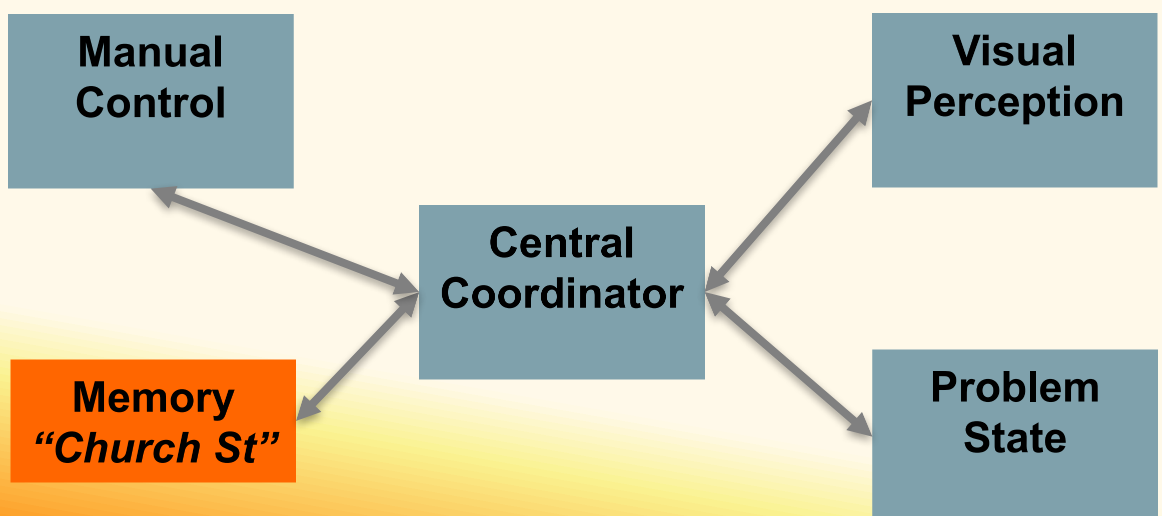
- 1 task = 1 cognitive model

- Multitasking =
  executing multiple models concurrently

Multitasking: Typing while driving

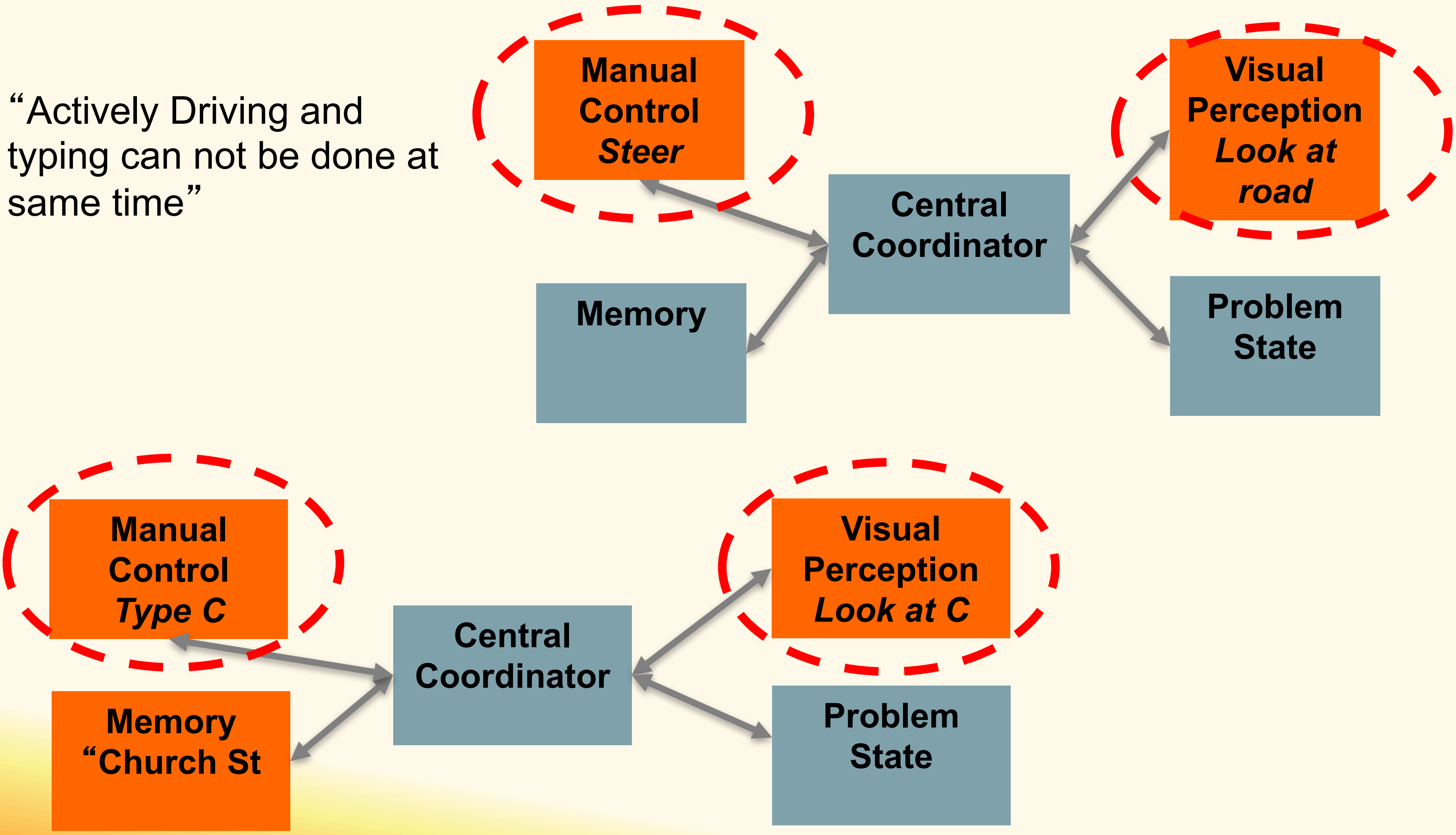
"Actively Driving and memory retrieval can be done at same time"





Multitasking: Typing while driving

"Actively Driving and typing can not be done at same time"



Models are not static

- Which module is active changes over time
  - See detailed example in appendix of slides

Example: Distract-R

See: http://cog.cs.drexel.edu/distract-r/

Advantages cognitive architectures

1. **Formal specification: One framework to describe behavior in multiple settings**
   - Compare: Newton's laws in physics
2. **Working code is detailed**
   - Difficult to be vague/unspecified about aspects
   - Question about the model? Look at the code
3. **Model reuse & predictions**
   - Test in novel settings (e.g., driving on different roads)
   - Multitasking: combine models for various multitasking situations
4. **Understand by building & active testing**

Disadvantages of architectures

1. Requires many details (all modules)
2. Some assumptions are hidden
   – E.g. Default parameter settings
3. Not always clear which component of model is critical/essential for behavior
4. Sometimes models are *too specific* or *not specific enough* for the process that you are interested in
   – e.g., ACT-R misses some details on human vision
5. Falsification is difficult

Today’s topics

- Why use models?
  - In science
  - In practice / industry
- What is a cognitive architecture?
  - What are the (dis-)advantages?
  - What is contrast with cognitive model?
  - Example: multitasking in ACT-R
- **What makes a good model?**
  - **Level of abstraction**
- **If you want to know more…**

Articles to read (required for exam)

1. Anderson, J. R. (2002). Spanning seven orders of magnitude: a challenge for cognitive modeling. *Cognitive Science*, *26*(1), 85–112.

1. Cooper, R. P., & Peebles, D. (2015). Beyond Single-Level Accounts: The Role of Cognitive Architectures in Cognitive Scientific Explanation. *Topics in Cognitive Science*, *7*, 243–258.

Try to get general gist
(study questions provided at end of slide deck)

Abstraction continuum

Abstraction continuum

- **Two perspectives:**
  1. **Newell (1990) Unified theories of cognition (discussed in Anderson, 2002)**
  2. **Marr (1982) Vision. Chapter 1 (discussed in Cooper & Peebles, 2015)**

Abstraction level

- **Newell: time bands**
- **Marr: levels**
- **You need to know the levels and their characteristics**
  (See appendix of slide deck, articles)
  - **Be able to determine what is best level of abstraction for given problem**
- **Models are not always 100% one band or level. These are continua.**
  - **Each has relatively more focus on one band / level**

Implications of abstraction

- **Abstraction is *always* necessary:**
  - Ignore (some parts of) 'lower' or 'higher' level
  - This makes research powerful:
    - No need to specify irrelevant 'details'
    - Focus on *relevant* issues

- **Issue: what degree of freedom do you take in (under-/over-) specifying a model?**
  - Can you defend each of its assumptions?
  - What aspects do you need to measure in your data to develop & validate your model?

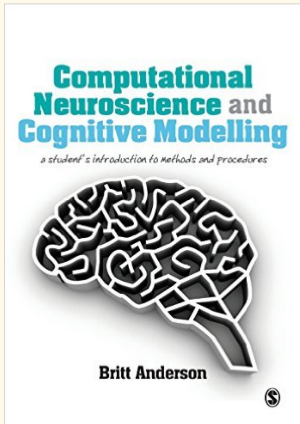
If you want to know more

- Cognitive Modeling (INFOMCM): block 2

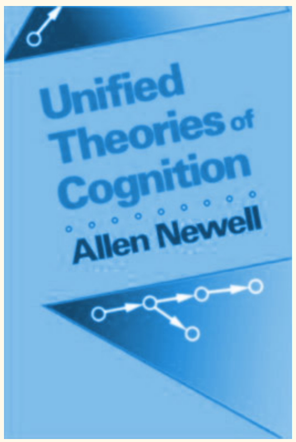
– Machine learning	Implementation	Ben Harvey
– Processing models	Algorithmic / Comp	Chris Janssen
– Bayesian models	Computational	Rick Nouwen & Frans Adriaans

- Programming: implement & test models in R
- Literature, lectures, presentations
- Suitable for students without Psychology degree! (who are interested)
  (in fact: aimed at!)

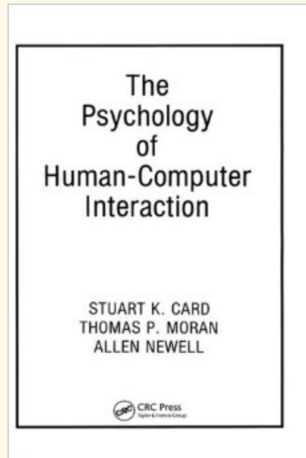
If you want to know more: textbooks



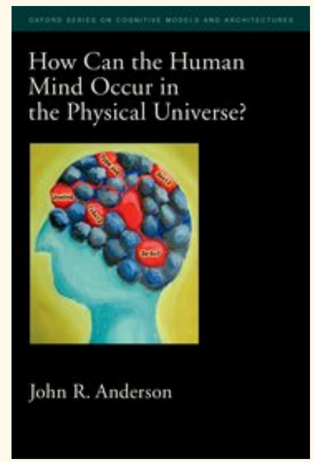
Accessible, general intro on variety of models



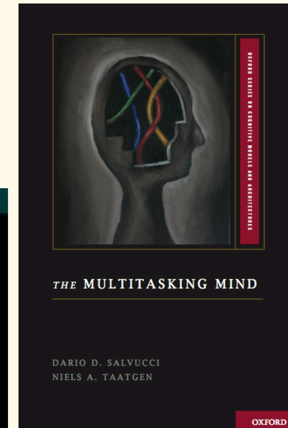
Classic for unified theories



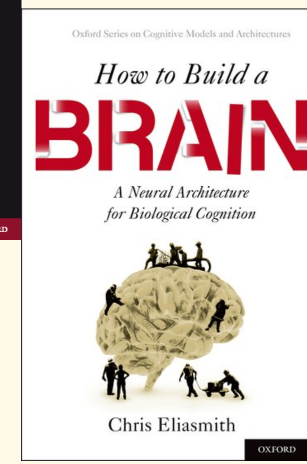
Human-Computer Interaction (older, but brilliant!)



Cognitive Architectures (esp Chapter 1)

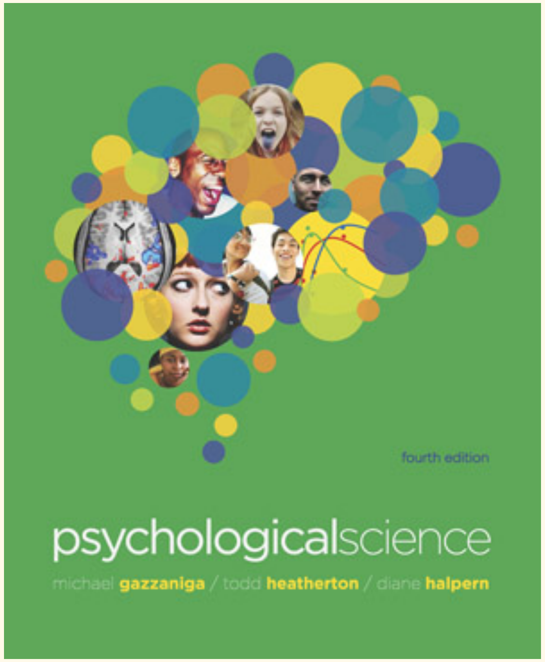


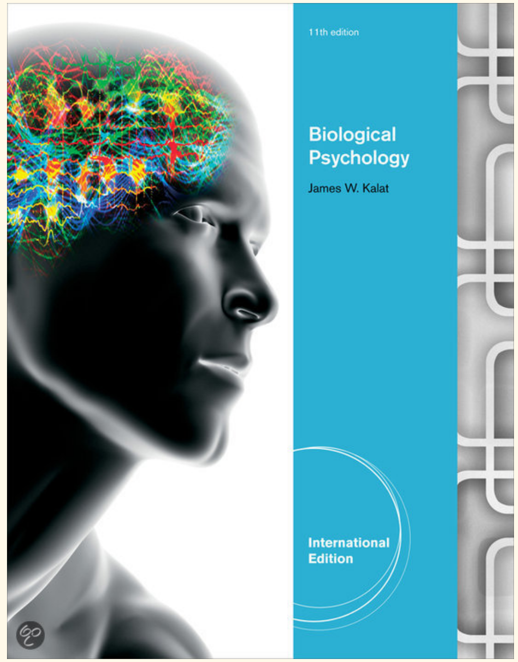
Multitasking (esp C1: abstraction & application)

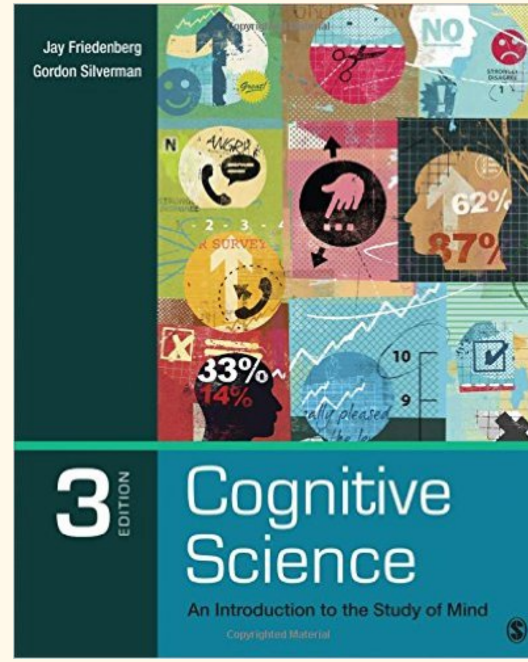


Neuroscience & Engineering

For more general psych background (not modeling)







- **M.S. Gazzaniga, T.F. Heatherton and D.F. Halpern (2011) Psychological Science (4th edition). ISBN 9780393913361. (general overview)**
- **Kalat (2013). Biological Psychology. 11th edition. ISBN: 9781111839529. (some knowledge of biology is useful)**
- **Friedenberg, J. & Silverman, G. (2015). Cognitive Science: an introduction to the study of mind (3rdedition). Thousand Oaks, CA.: Sage (more cognitive science / formal → most relevant to AI)**

Next week

- Different location (check course schedule)

Today's topics

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  - In science
  - In practice / industry
- What is a cognitive architecture?
  - What are the (dis-)advantages?
  - What is contrast with cognitive model?
  - Example: multitasking in ACT-R
- What makes a good model?
  - Level of abstraction
- If you want to know more…

Questions?

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Study questions lecture (not bullet proof)

- What are benefits & disadvantages of using models?
- What are the benefits of models for industry/practice?
- What is a unified theory of cognition?
- What is difference between cognitive model and cognitive architecture?
- What is relationship of cognitive models and architectures with strong/weak AI, Turing machine, over & under constrained theory
- What are different levels of abstraction, their characteristics, benefits, disadvantages (Newell and Marr perspective)
- Be able to apply these principles to case studies

Study questions Anderson (not bullet proof)

- Describe each of Newell’s 4 bands. How do they relate to time units and systems?
- What is the decomposition thesis?
- What is the relevance thesis?
- What is the modeling thesis?
- Why is the “unit-task” level useful for each thesis?

Study questions Cooper & Peebles (not bullet proof)

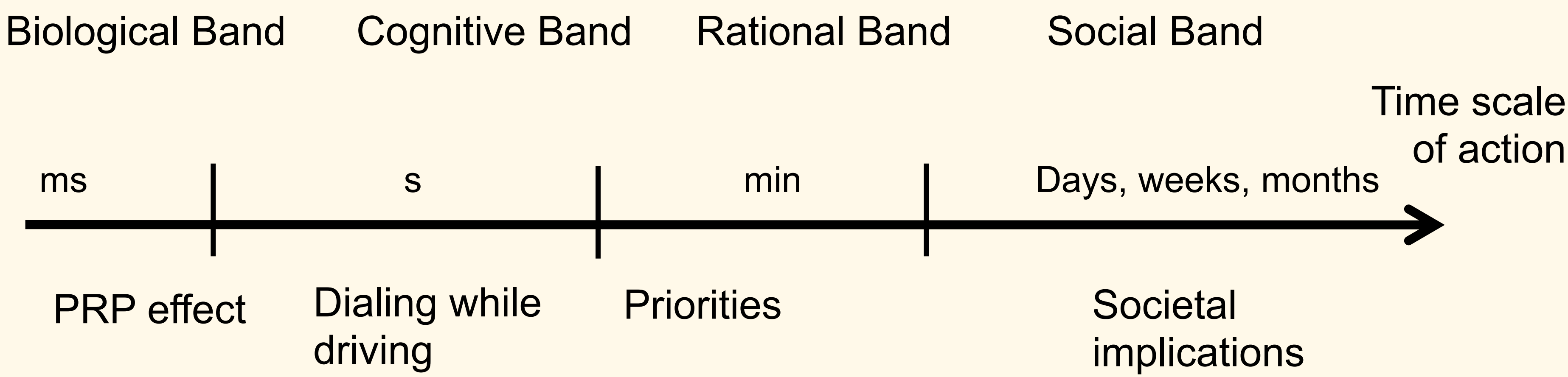
- Describe each of Marr’s 3 levels
- What was Marr’s criticism of cognitive systems that were not rooted in CL?
- What are limitations of CL?
- What are limitations of IL?
- What is the value of tying the CL or IL to the ARL?
- What is the value of specifying a model in a cognitive architecture (or with interacting subfunctions)?

Additional slides to help understand articles

Abstraction continuum (Newell, 1990)

- In what process are you interested?
- What are the steps that are involved in this process over time?
- “Through which lens are you looking”?

Abstraction continuum; time scale of action

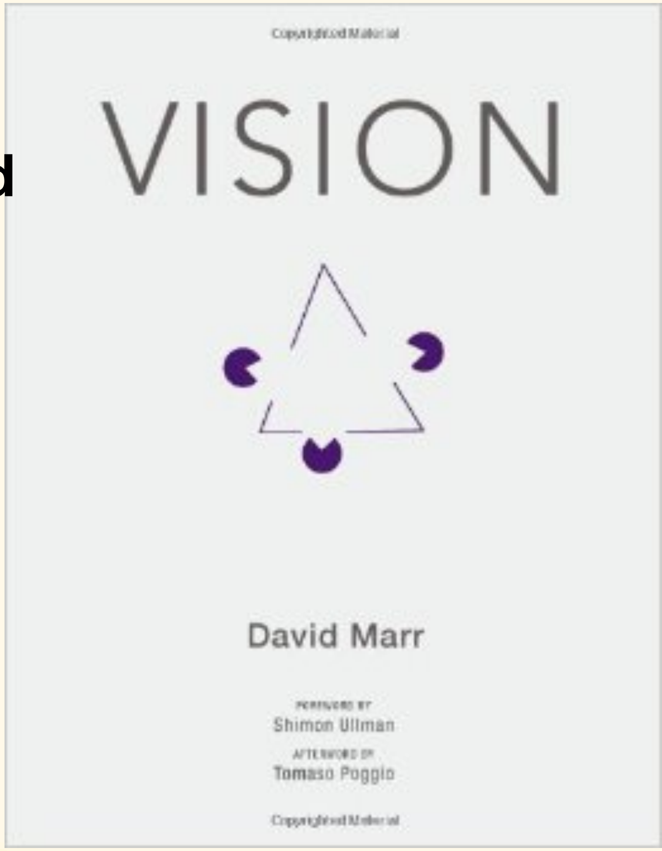


Abstraction continuum

- **Alternative view:**
  David Marr (1982) Vision Chapter 1
- **3 levels:**
  - **Computational theory**
  - **Algorithmic theory**
  - **Implementation theory**

More detailed

- **Each level is important**
- **Each level explains *different* aspects of behavior**



Implications of time scale (1)

- Choice influences:
  - What you *can* and *should* measure
  - What you should specify in your model
- Cognitive band: behavioral data
  - Reaction times, accuracy, choices, eye-gaze (sometimes: fMRI, EEG)
- Biological band: data for very short time intervals
  - Eye-gaze, EEG, fMRI, …

Implications of time scale(2)

- **Abstraction is *always* necessary:**
  - Ignore (some parts of) ‘lower’ or ‘higher’ level
  - This makes research powerful:
    - No need to specify irrelevant ‘details’
    - Allows to focus on *relevant* issues

- **Issue: what degree of freedom do you take in (under-/over-) specifying a model?**
  - Can you defend each of its assumptions?

		Biological Band	Cognitive Band		Rational Band	Social Band
emailing	tasks	basic cognition, muscle movements	type key, move mouse	delete message, search for text	respond to email, edit address book	keep in touch with family & friends
	measures	neural data, motion data	keystrokes, mouse position	time on task, errors, content	time on task, errors, content	satisfaction, pleasure
phoning	tasks	basic cognition, muscle movements	press button, say word	dial number, say sentence	call friend, check voice mail	keep in touch with family & friends
	measures	neural data, motion data	button latency, speech latency	time on task, errors, content	time on task, errors, content	satisfaction, pleasure
driving	tasks	basic cognition, muscle movements	steer, accelerate	change lanes, follow car	drive to store, find gas station	drive safely, save gas
	measures	neural data, motion data	steering angle, lane position	maneuver time, lane position	time on task, incidents	crashes, incidents

phoning & emailing

driving & phoning

milliseconds — seconds — minutes — days/weeks/months

Time Scale of Action

Figure 1.3: The Abstraction Continuum (derived from Newell, 1990).

(From Salvucci & Taatgen (2011) The multitasking mind

Abstraction continuum

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  David Marr (1982) Vision Chapter 1
- **3 levels:**
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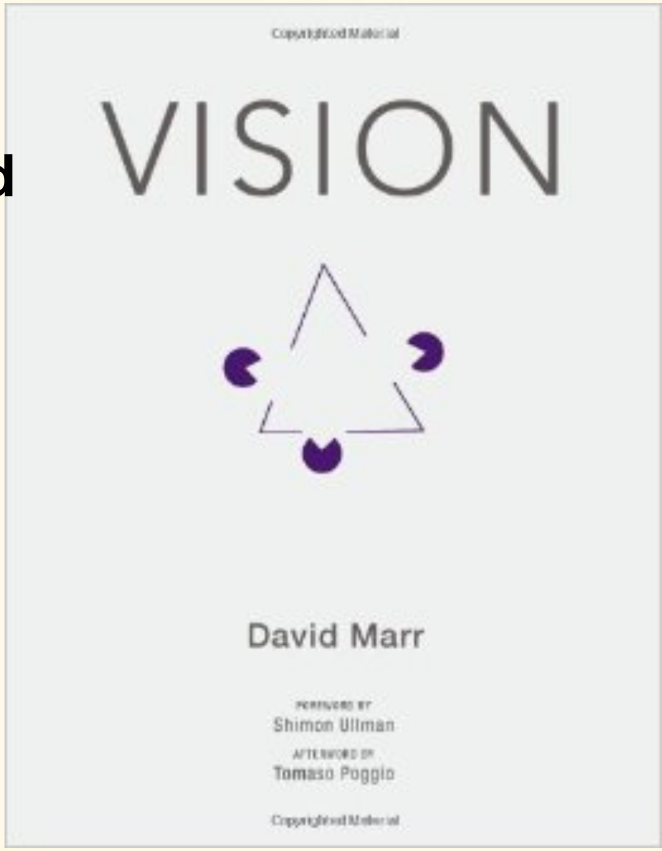
  - **Algorithmic theory**
  - **Implementation theory**

More detailed

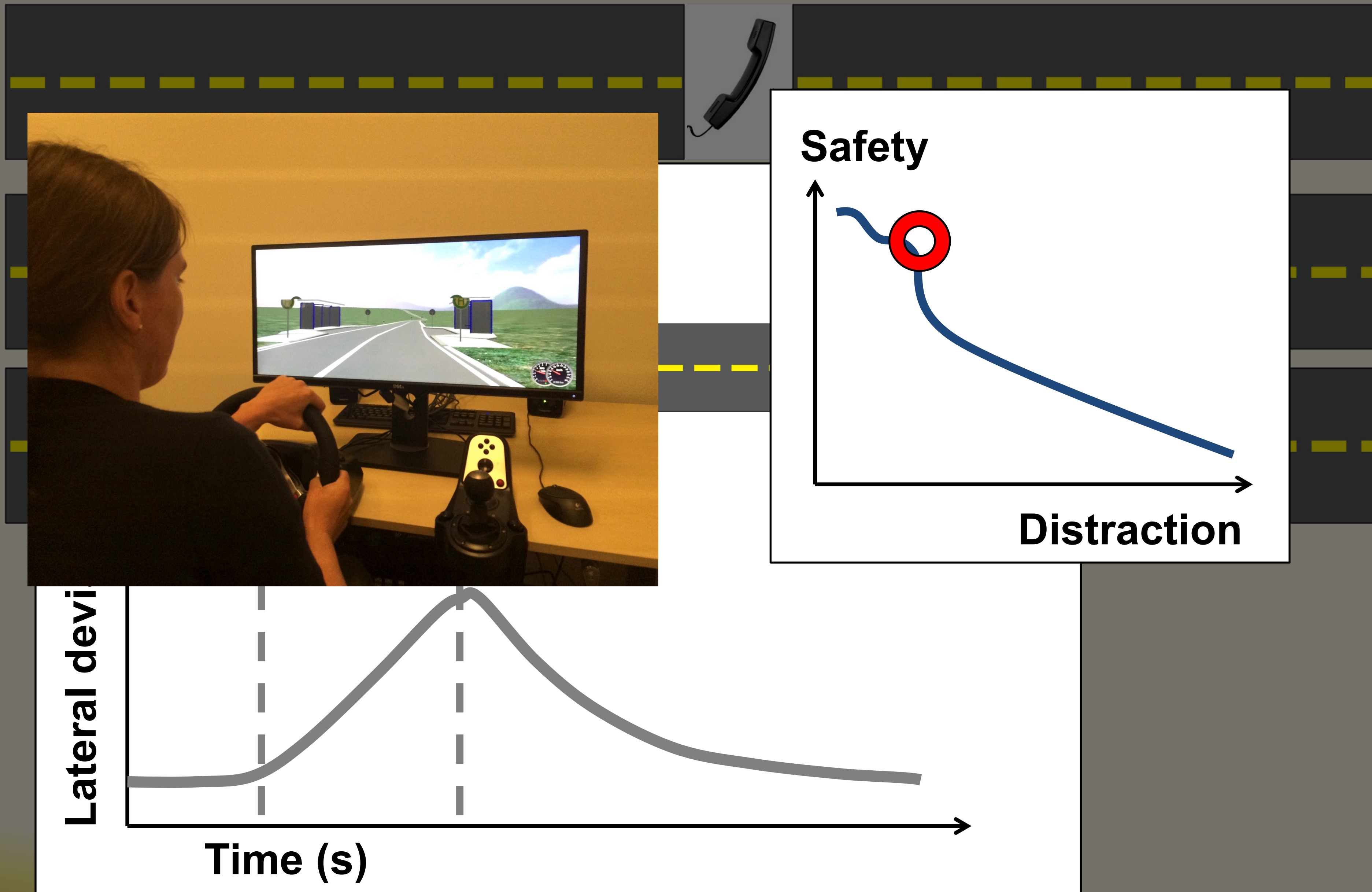
- **Each level is important**
- **Each level explains *different* aspects of behavior**



Marr: Computational level

- Goal
  "*WHY* do we do what we do"?
- What they do not answer:
  - What is done? What strategies are used? (algorithmic)
  - How does brain/neurons achieve this? (implementation)
- Common characteristics:
  - Small set of equations explains behavior
  - Explanation involves characteristics of statistics of the environment (e.g., adaptive argument)

Example: Computational level (with algorithmic flavor)


Safety
Distraction
Lateral devi
Time (s)

See also video clip of example (computational model with algorithmic flavor)

https://youtu.be/rQhj0vjVZFU

Marr: Algorithmic level

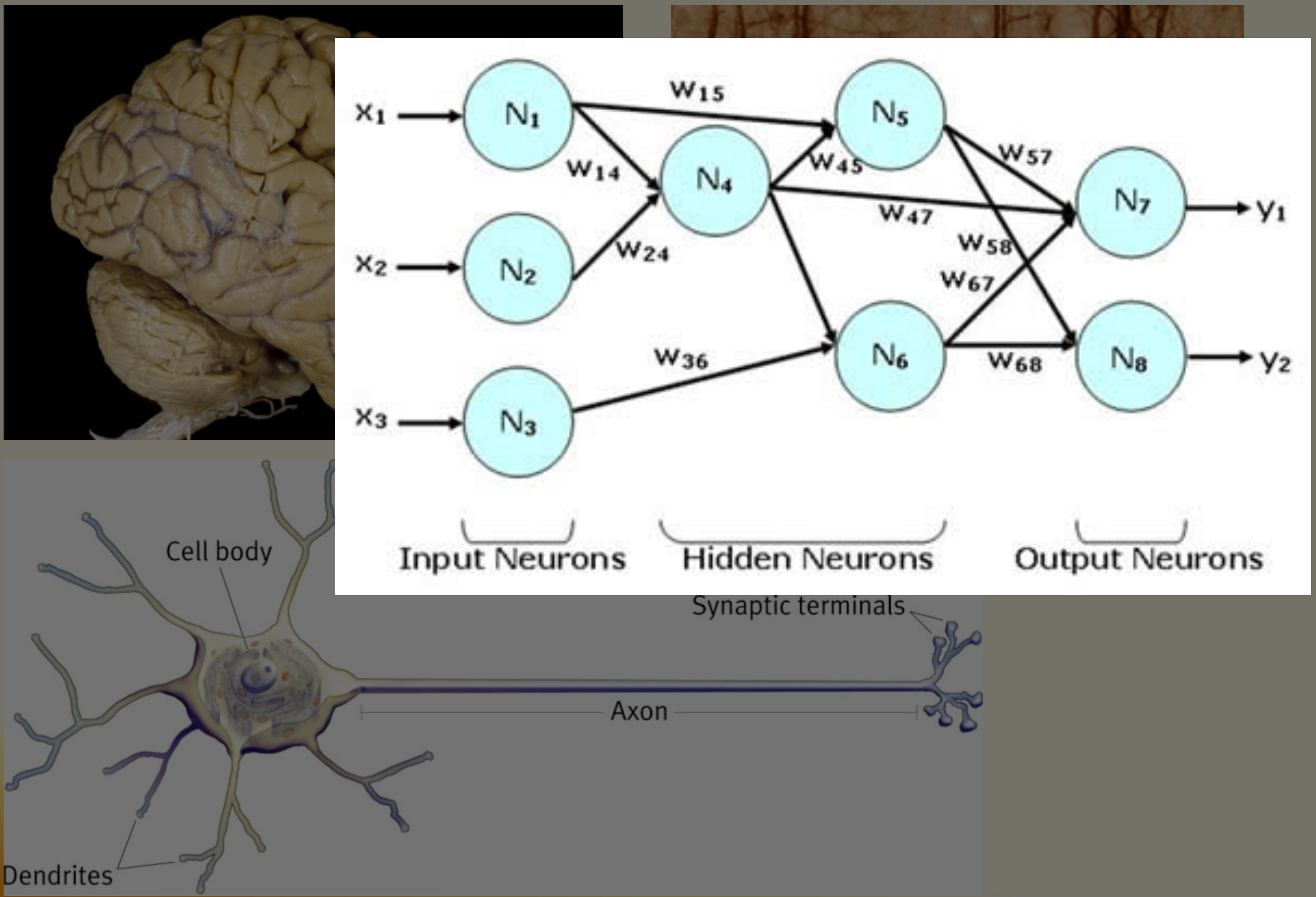
- Goal :
  - How is a computational theory implemented?
  - What is the “input”, what is “output”
  - What type of algorithm/strategy solves this problem?
- What they do not answer:
  - *Why* is implementation like this? What is purpose (computational)
  - What is physical implementation? How brain achieves this (implementation)
- Common characteristics:
  - Detailed algorithms
  - That describe aspects of the process

Example: Algorithmic level

Marr: Implementation level

- Goal:
  - What is the physical implementation?
- What they do not answer:
  - Why is the implementation like this? What is the purpose (computational)
  - What is done? What strategies? (algorithmic)
- Common characteristics:
  - Describe WHERE in the brain the process occurs
  - WHAT areas are connected to each other and HOW
  - Many many minor details, small time scale

Example: Implementation level



Example implementation level

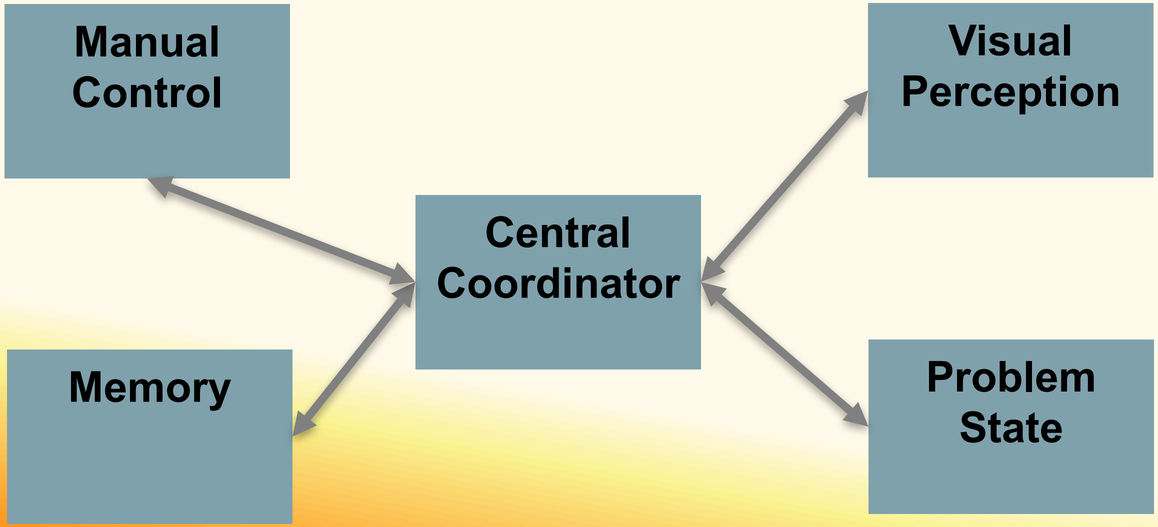
- (Artificial) Neural networks:
  - E.g. Learning of past tense
    (e.g., Rummelhart & McClelland, 1986)
- Good neuroscience models

- Architecture oriented implementation models…
  - Chris Eliasmith (U. Waterloo)
    - http://arts.uwaterloo.ca/~celiasmi/
  - Randall O’Reilly (U. Colorado)
    - http://psych.colorado.edu/~oreilly/

Detailed slide process over time

Example 1: Type in address

- **Which functions are achieved & by which module?**



Type in address

Executed *functions*:

- Look at the phone for address (vision)
- Look at sat-nav (vision)
- Store address in memory (memory)
- Type address (motor)
- Remember where you are (problem state)
- Execute actions in the right order (central coordinator)

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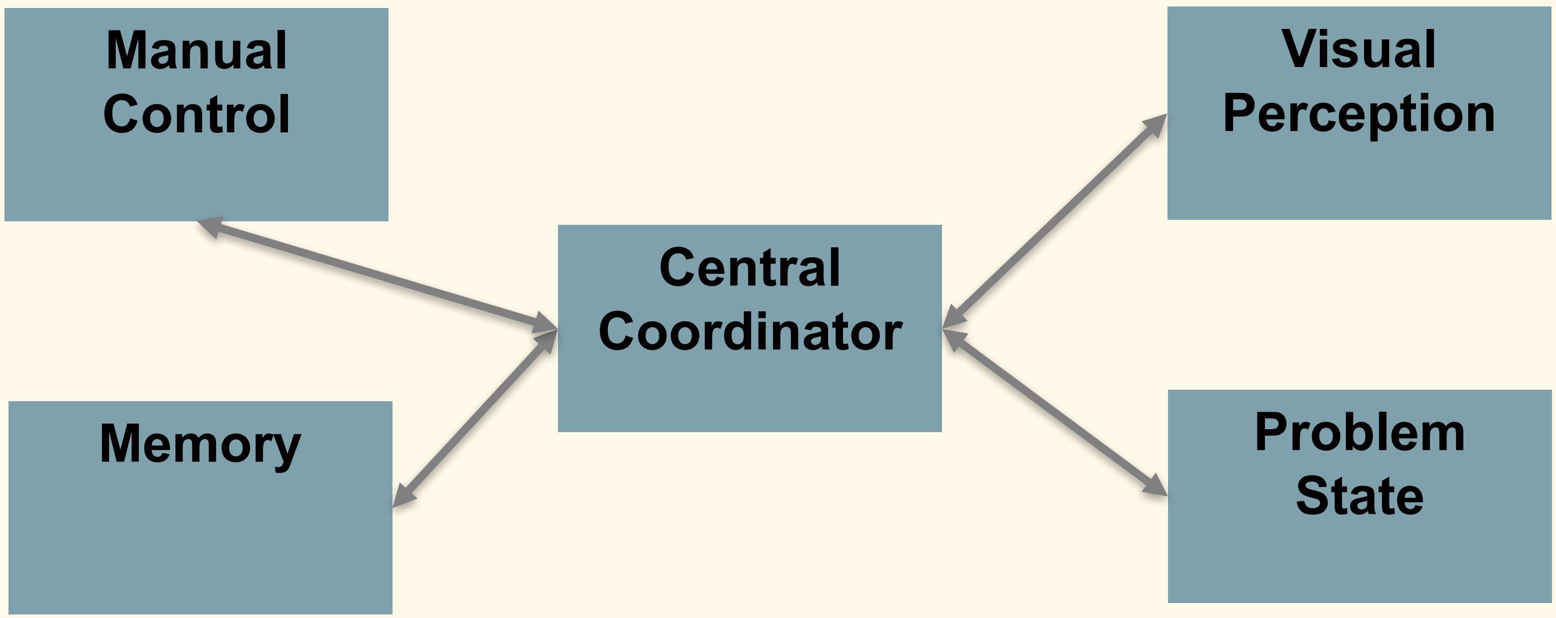

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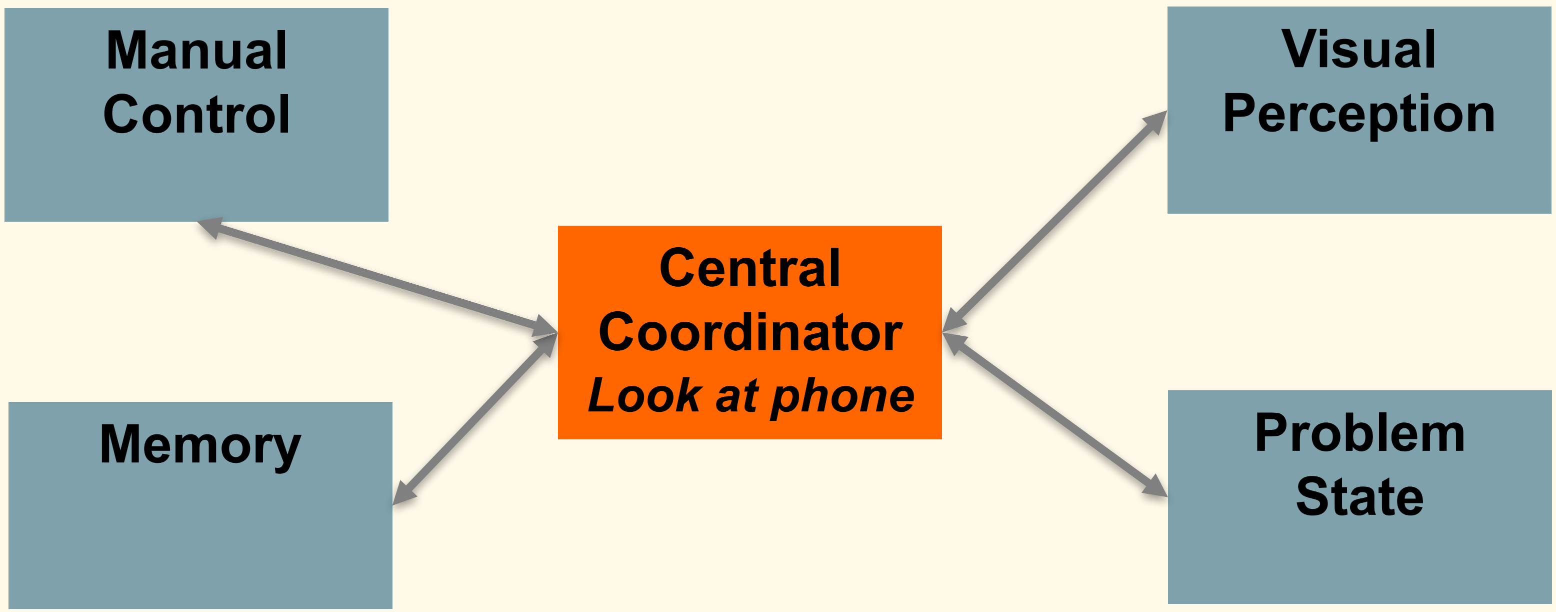

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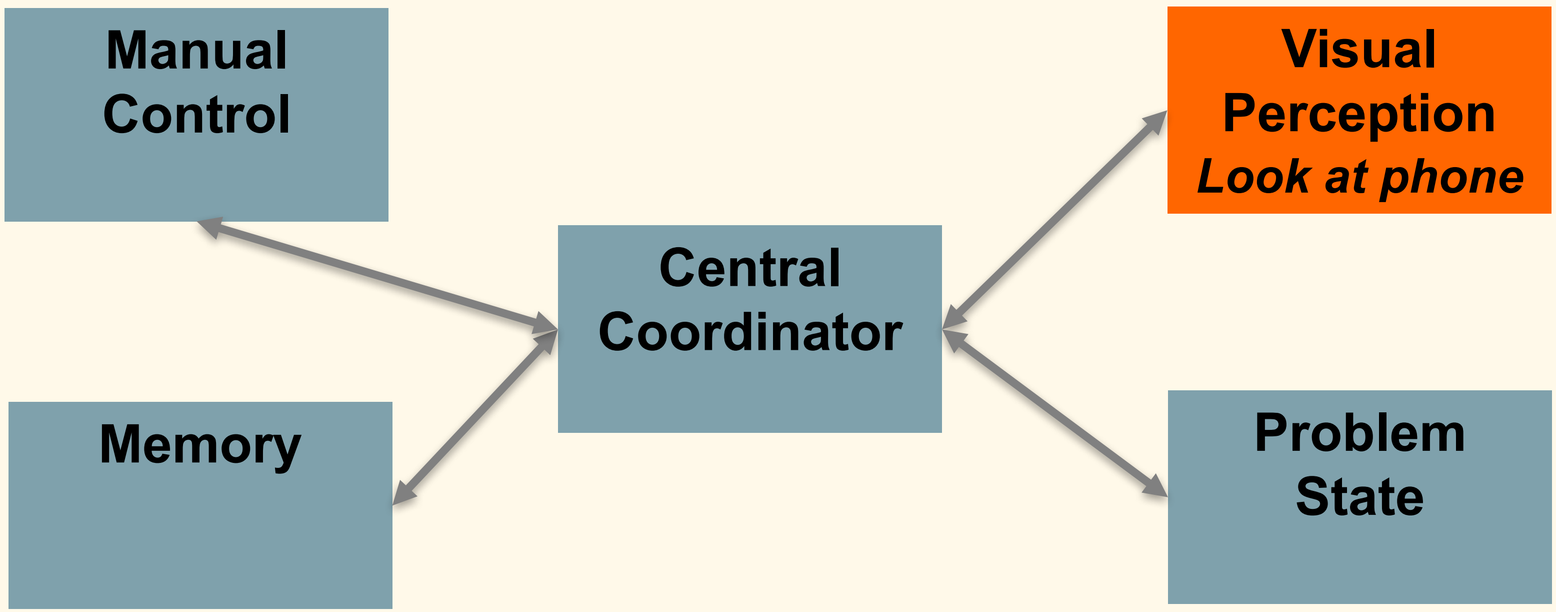

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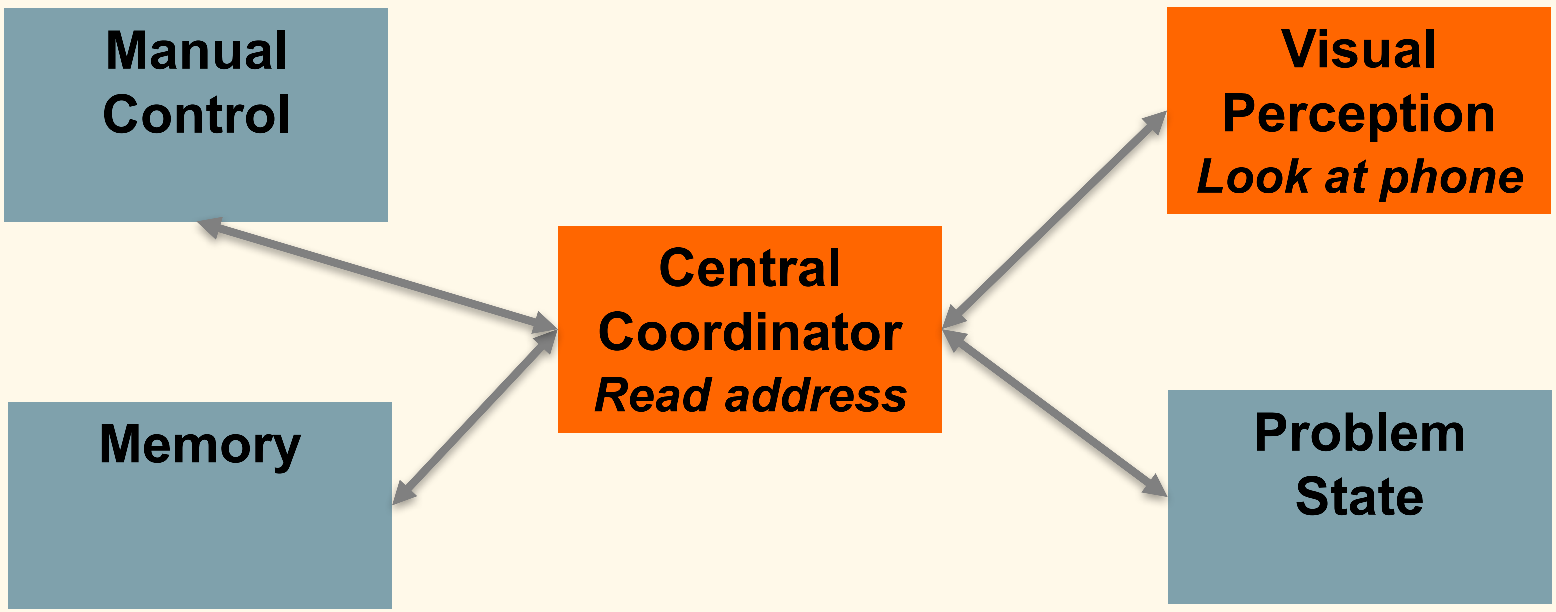

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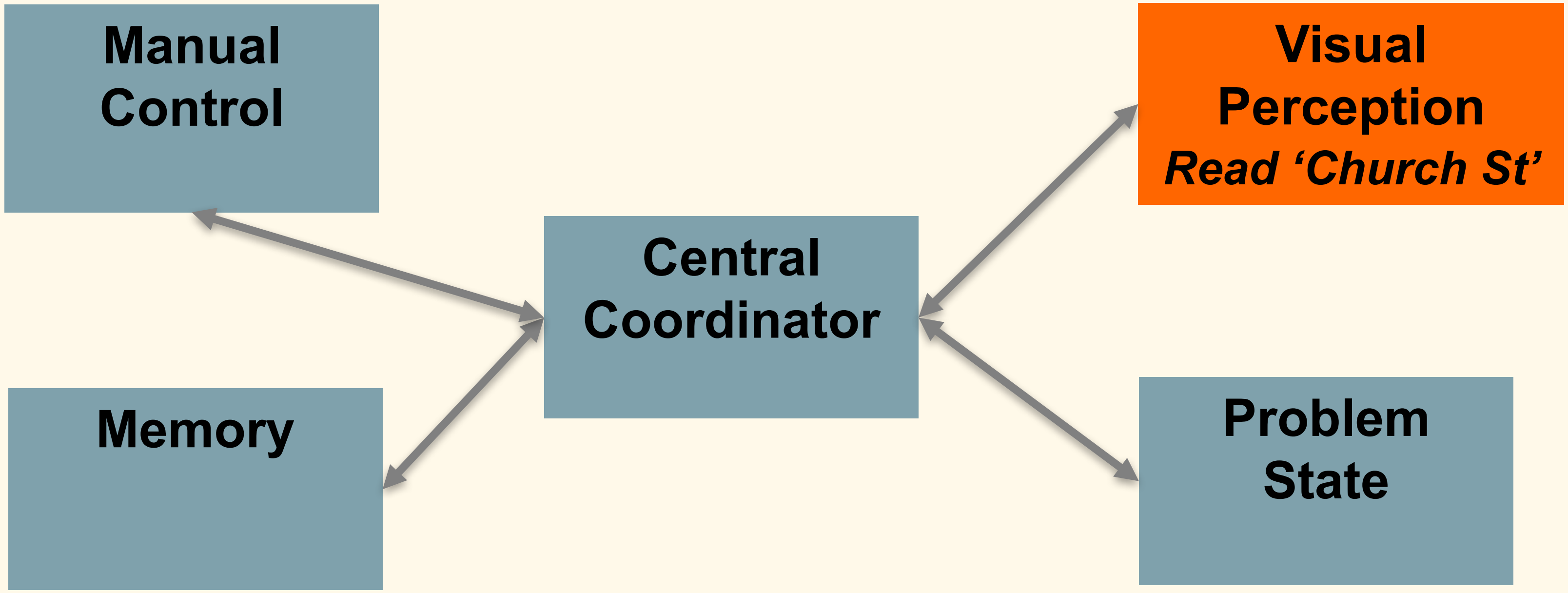

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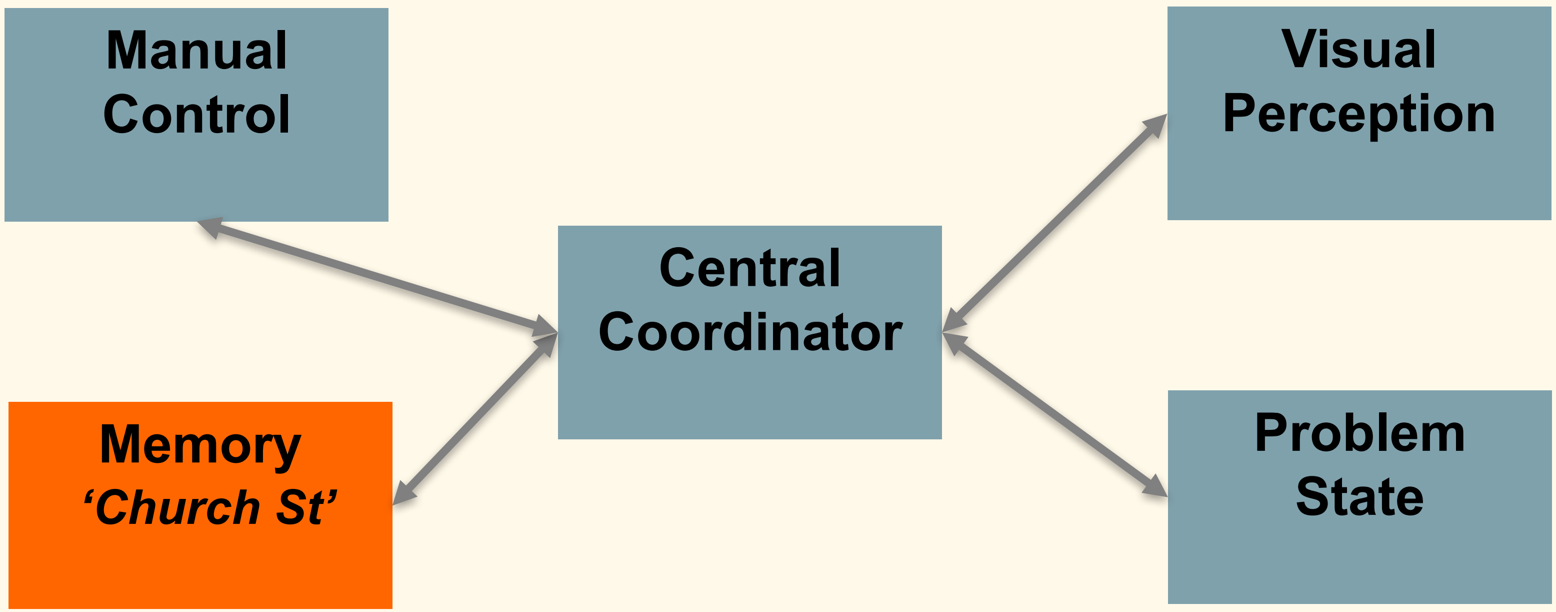

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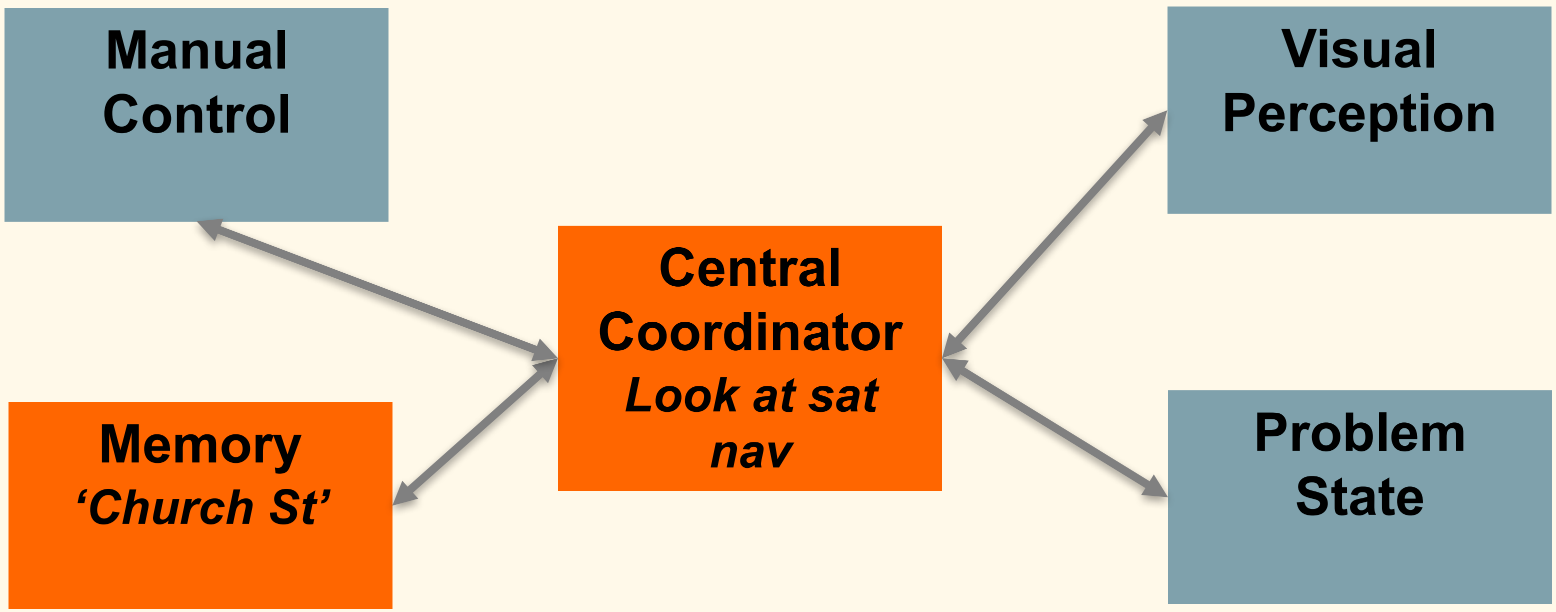

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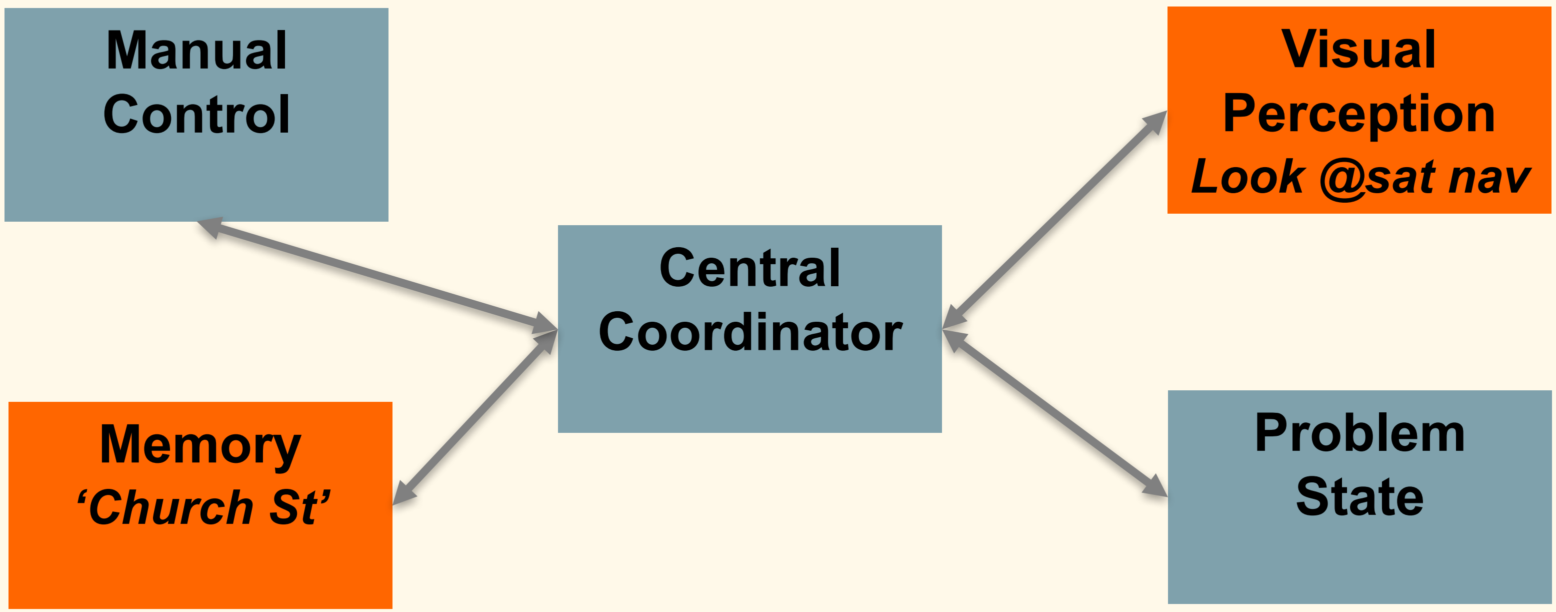

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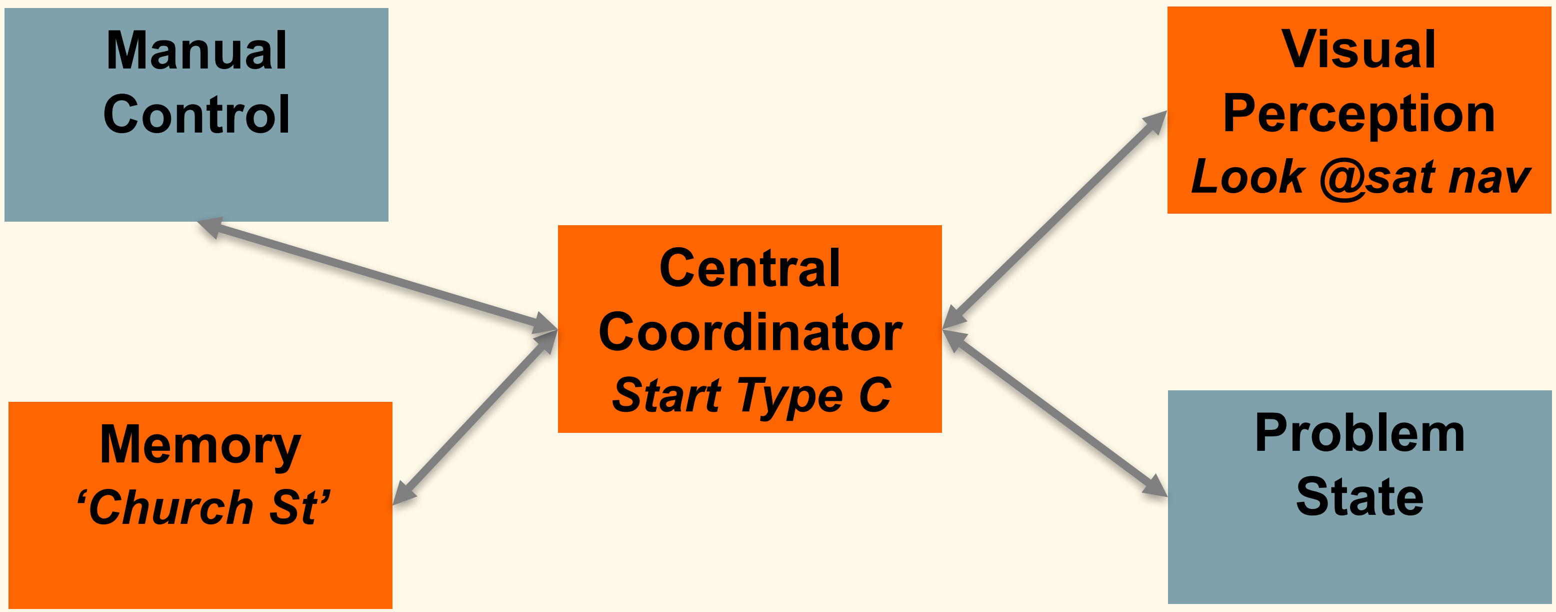

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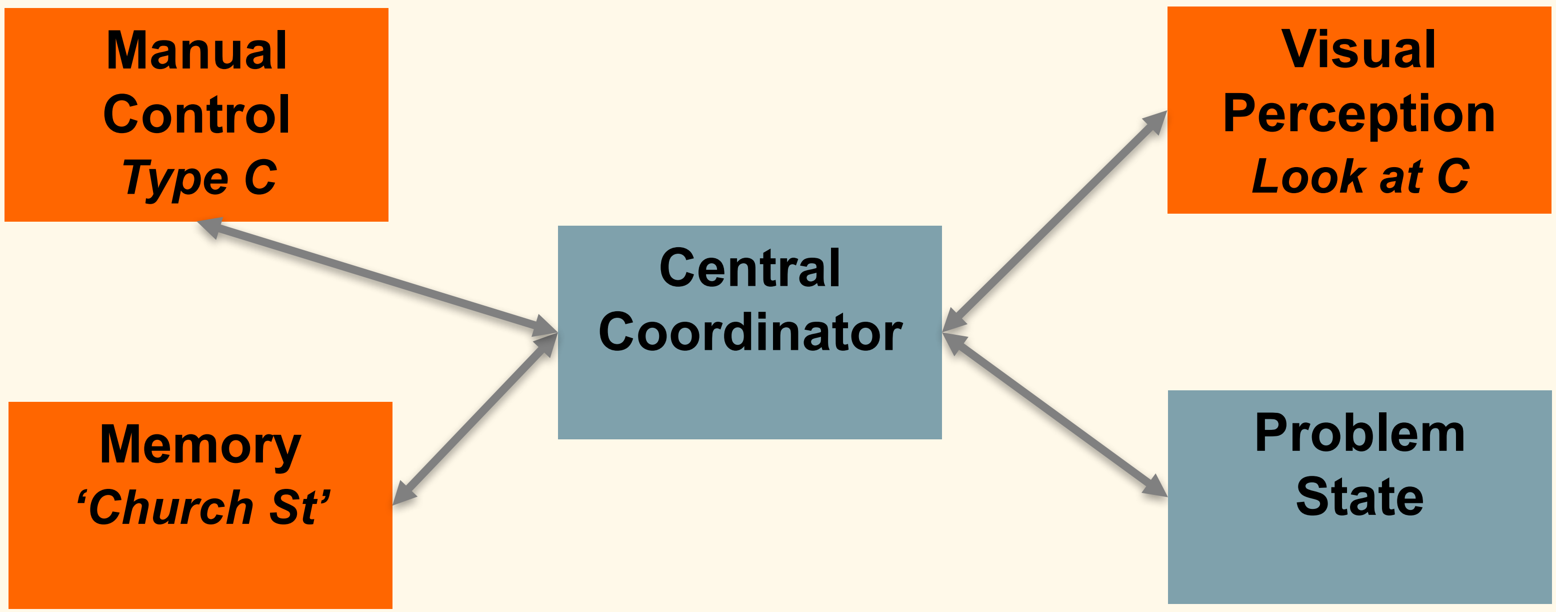

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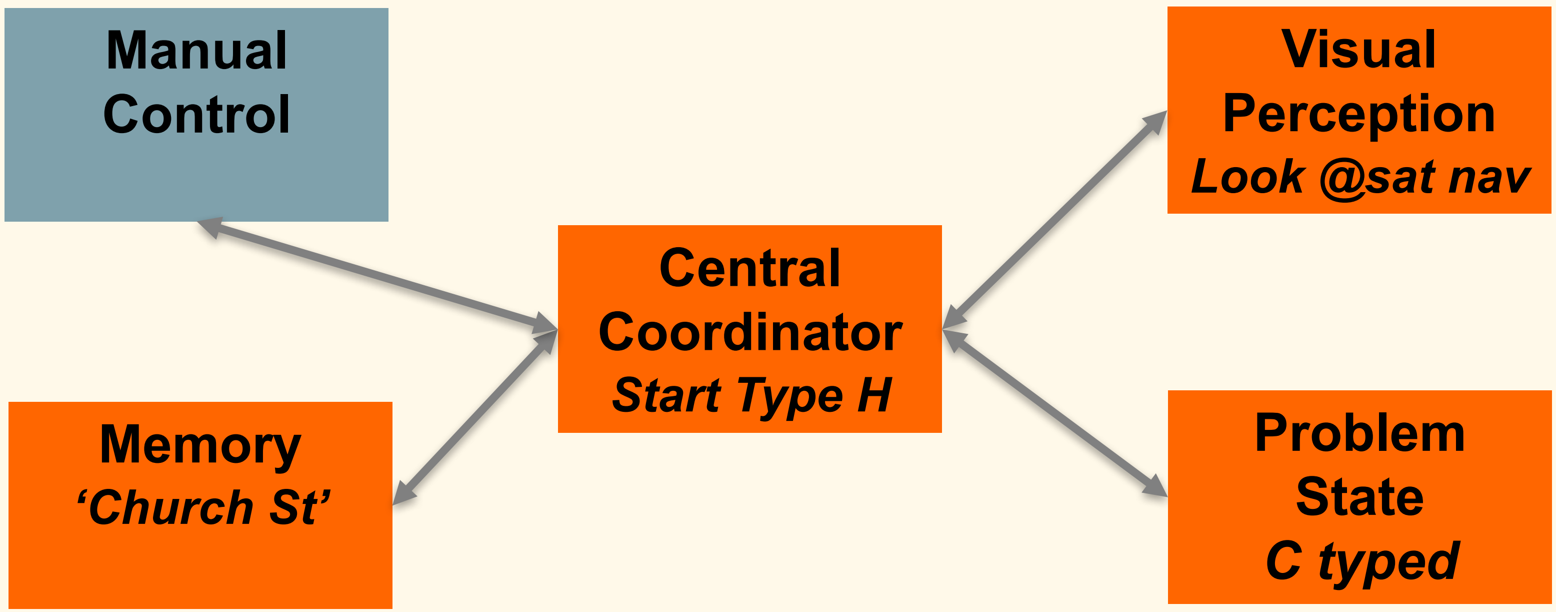

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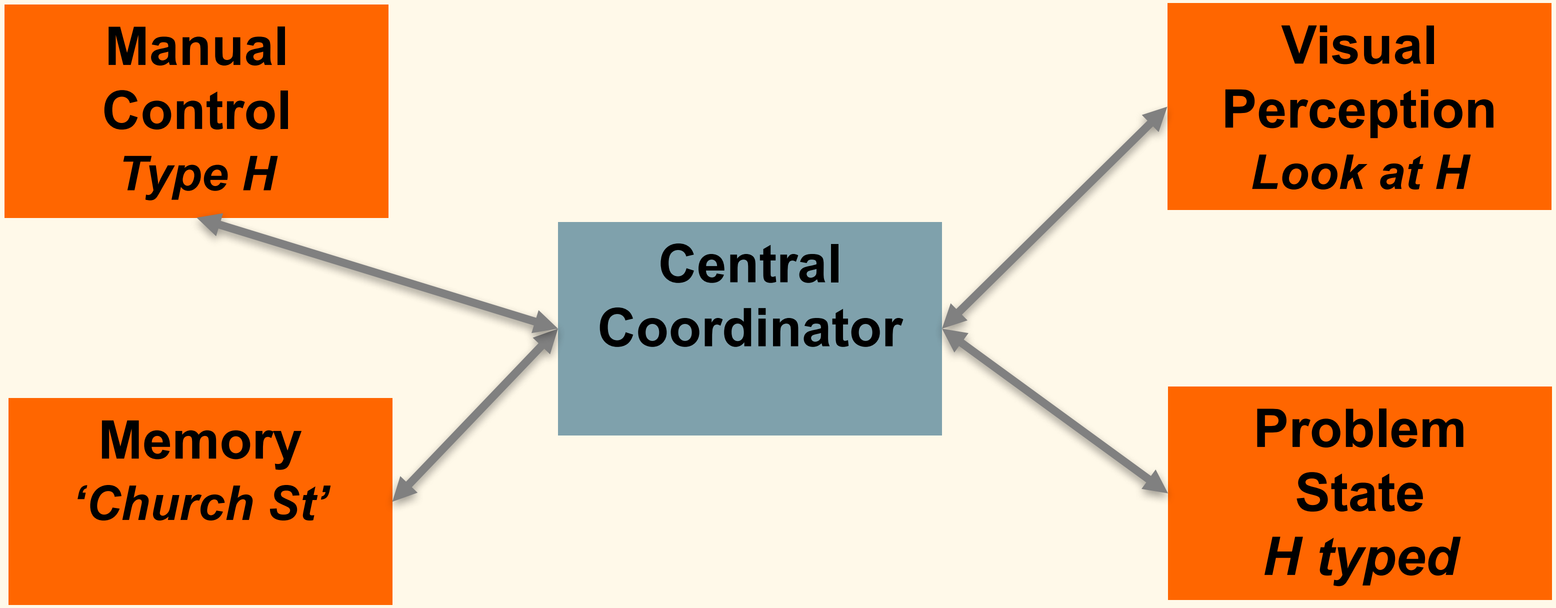

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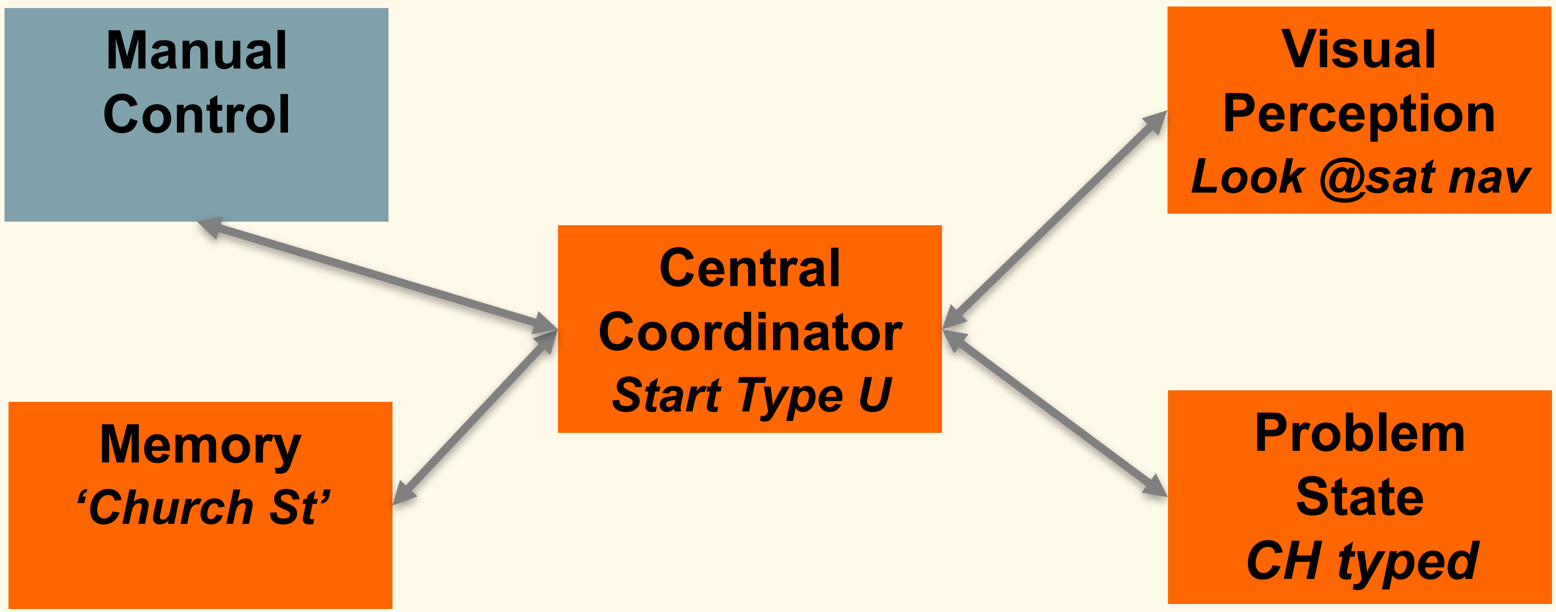
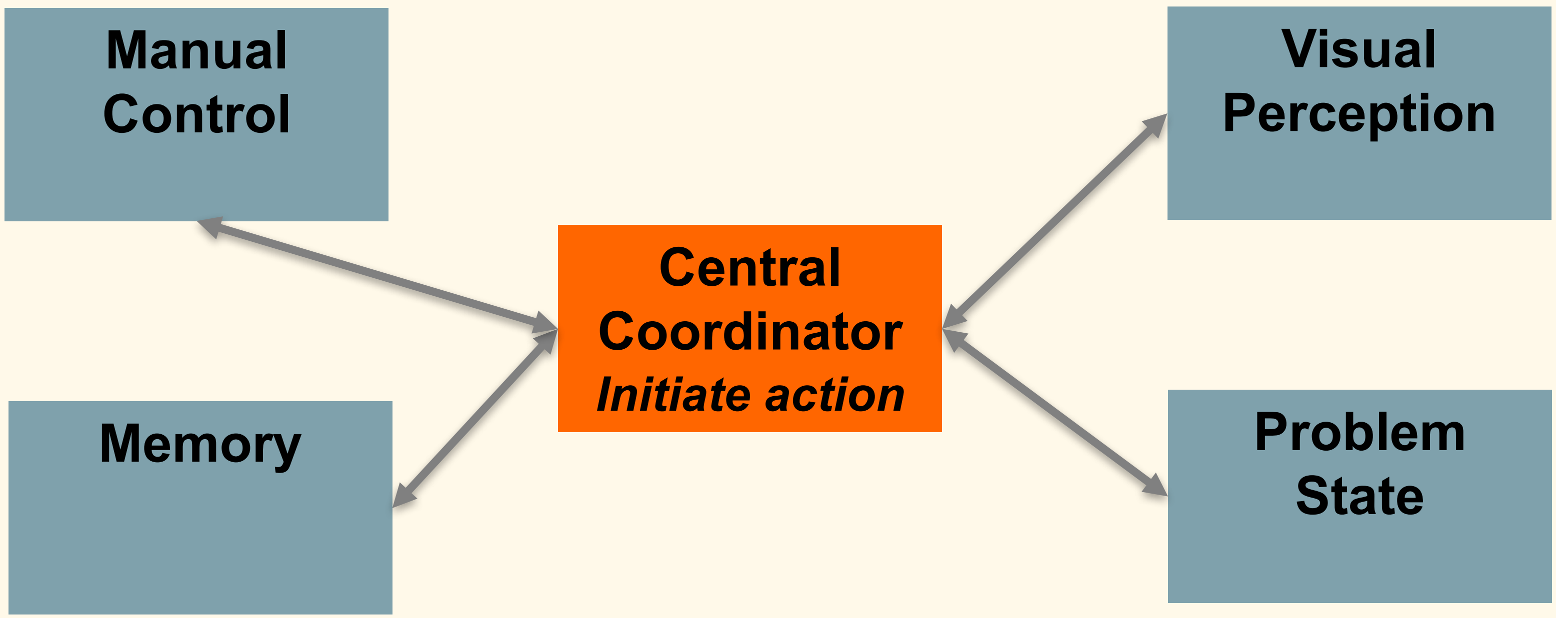


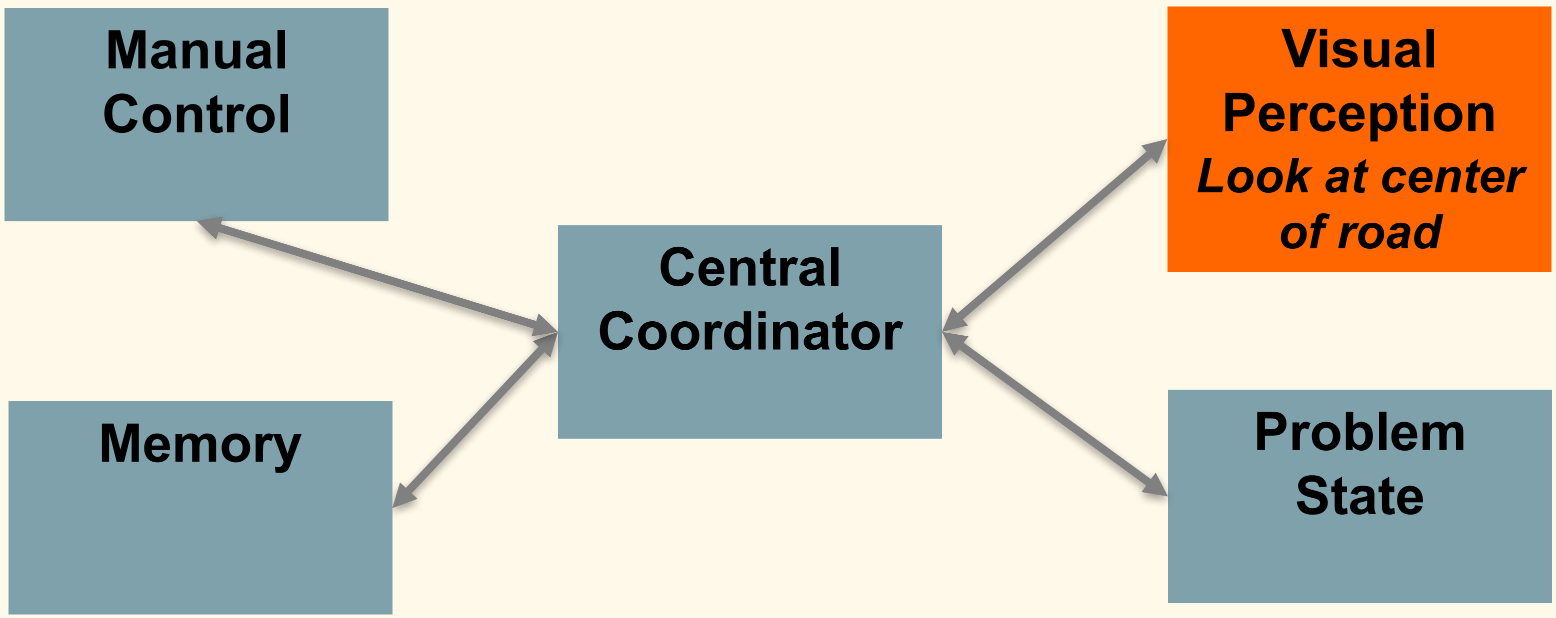
Example 2: Drive simulated car

- Executed *functions*:
  - Look at road (vision)
  - Identify center of road (vision)
  - Determine distance to center ("Black box")
  - Use steering wheel to improve lateral position (manual)

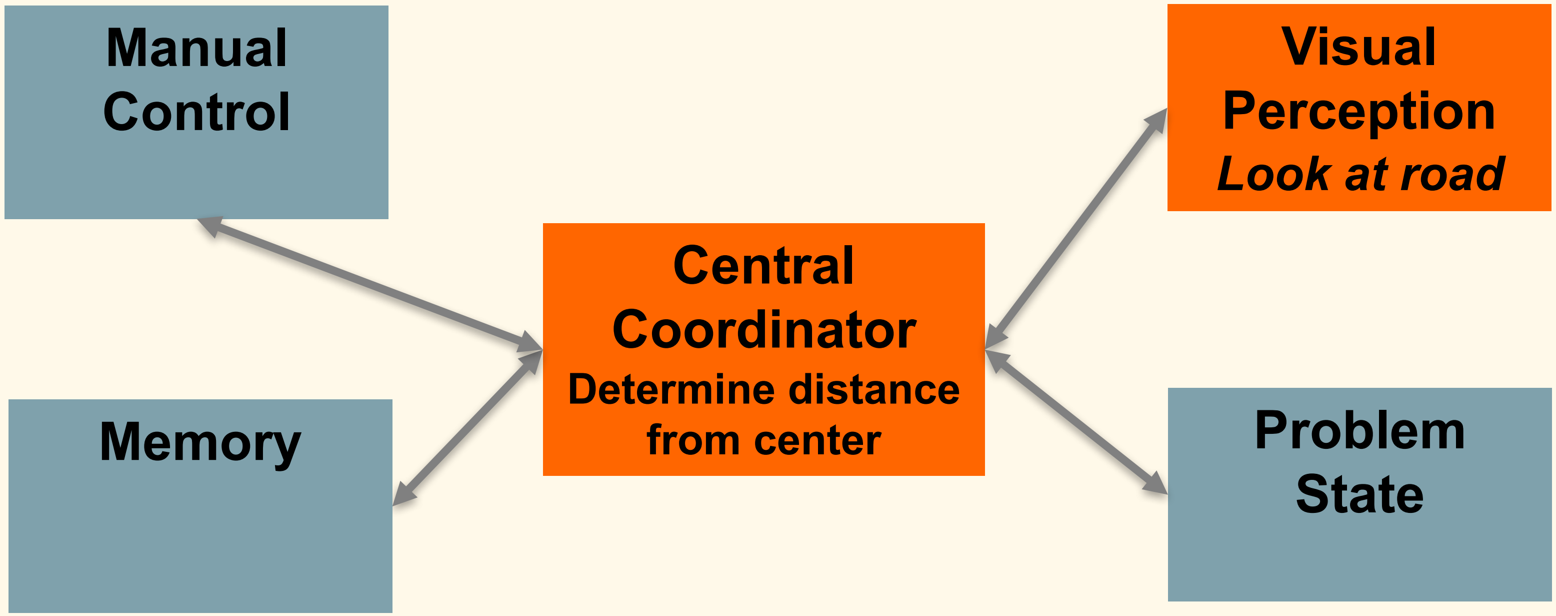
Simulated driving



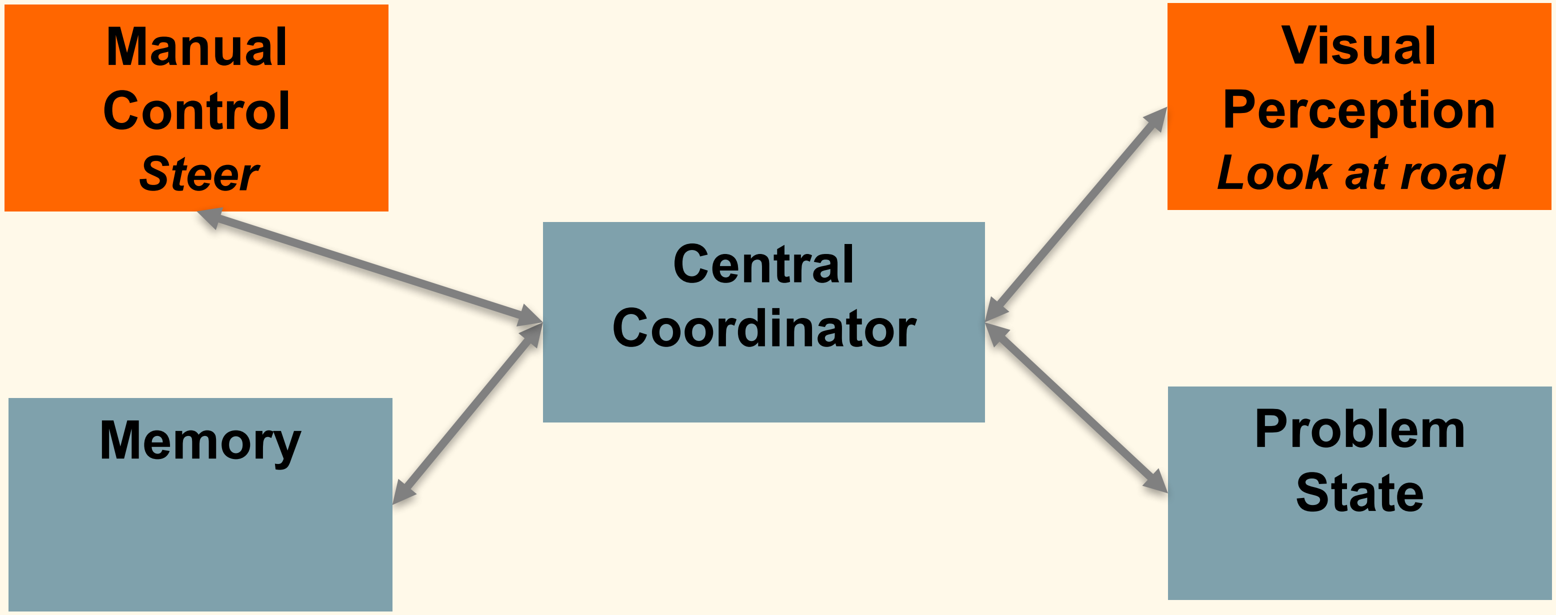
Simulated driving



Simulated driving



Simulated driving



Multitasking

- **2 or more tasks "concurrently" (or in rapid succession)**