



HUMAN PERFORMANCE

LECTURE 2: COGNITIVE MODELLING & INFORMATION PROCESSING

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TODAYS LECTURE:

- What is Cognitive Modelling.
- Construction of models.
- Focus on a particular cognitive model:
 - Choice-reaction time modelling.
- Information-processing and associated issues.
- Focus on sub-set of information-processing models
 - Spreading-activation and Connectionist models.

COGNITIVE MODELLING

- Aims to scientifically explain basic cognitive processes and how they interact.

We want to know how the mind works:

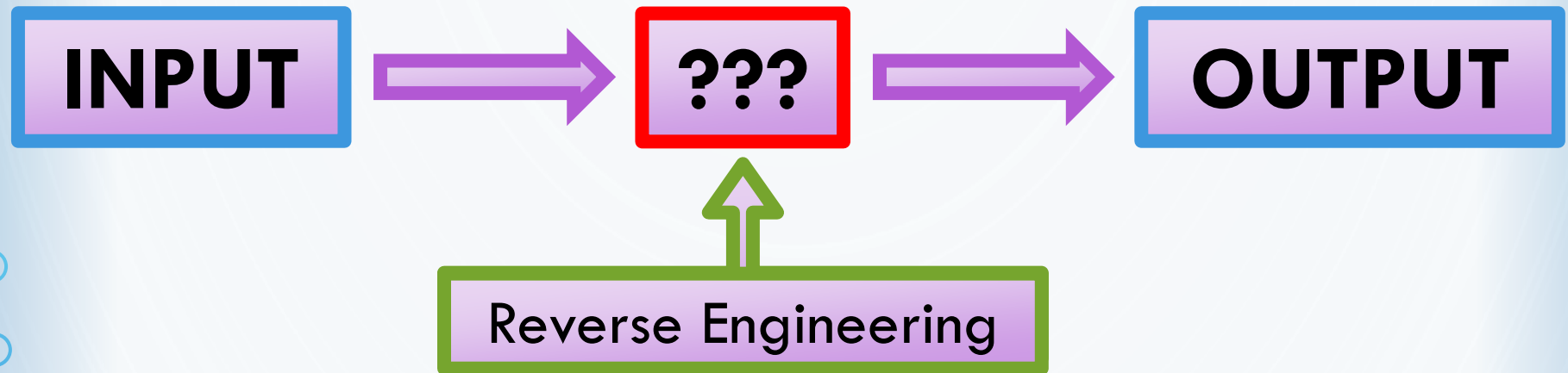
- How we process information and act on it.
 - How we learn, generalize, and memorize.
 - How we think, reason, plan, and make decisions
-
- ☐ This has implications for subsequent performance.
 - ☐ Comparing principles of a model to human behaviour allows us to test and refine theories.

COGNITIVE MODELLING

- A model is a very explicit theory regarding our mind's processing.
- Tends to be described in formal, mathematical, or computer languages.
- Differs from conceptual models, which use verbal descriptions of theoretical assumptions.

COGNITIVE MODELLING

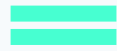
- Model is only accepted as accurate if it can predict how a participant will perform on a task.



Chronometric: An accurate model of Cognition should be able to predict how long it takes a real person to perform a task (See Ponser, 1978)

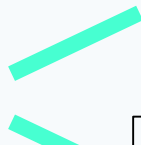
Cognition: Levels of description

Semantic/
Knowledge

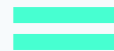


Goals, intentions & personal meaning, supporting adaptation to external environments. Guides our intelligence

Symbol
Processing

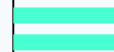


Algorithm



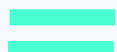
Formal specification of program for symbol manipulation

Functional
Architecture



Real-time processing operations supporting symbol manipulation

Physical/
Biology



Physical, neuronal representation of processing

“Classical theory” (Newall, 1982; Pylyshyn, 1984)

Cognition: Levels of description

Semantic/
Knowledge

**Cognitive Models
focus on this level**

Personal meaning,
to external
our intelligence

**Symbol
Processing**

Algorithm

Formal specification of
program for symbol
manipulation

**Functional
Architecture**

Real-time processing
operations supporting
symbol manipulation

Physical/
Biology

Physical, neuronal
representation of processing

Cognition: Levels of description

- **Symbol-processing level:**
 - Here we find differences between individuals.
 - Not at the algorithm level but at the functional architecture level.

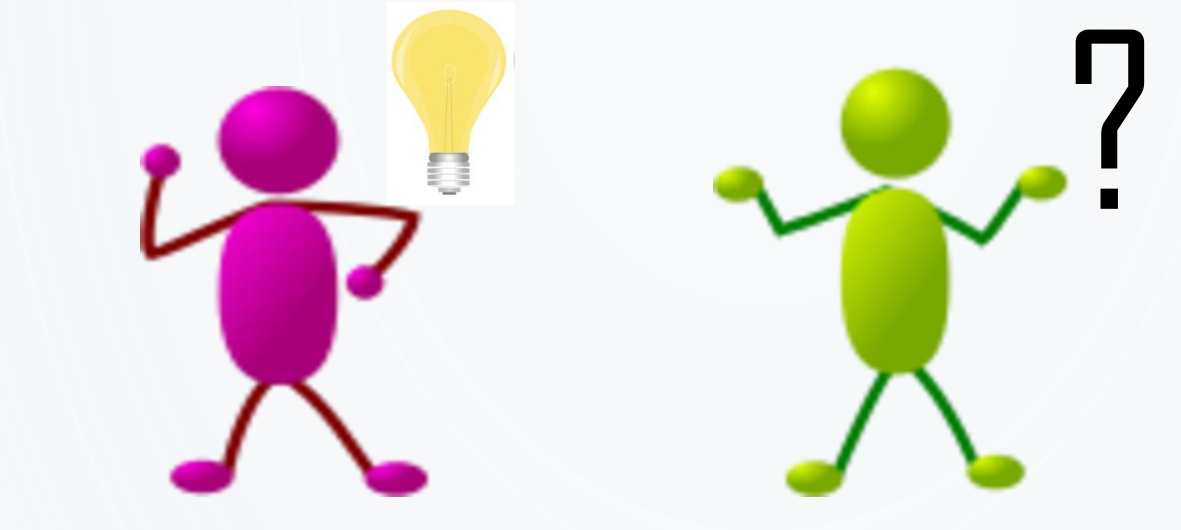
- **Example:**



- Both run same algorithm for word processing programme.
- But architecture is different meaning one may be quicker.

Cognition: Levels of description

- **The same applies to human performance:**



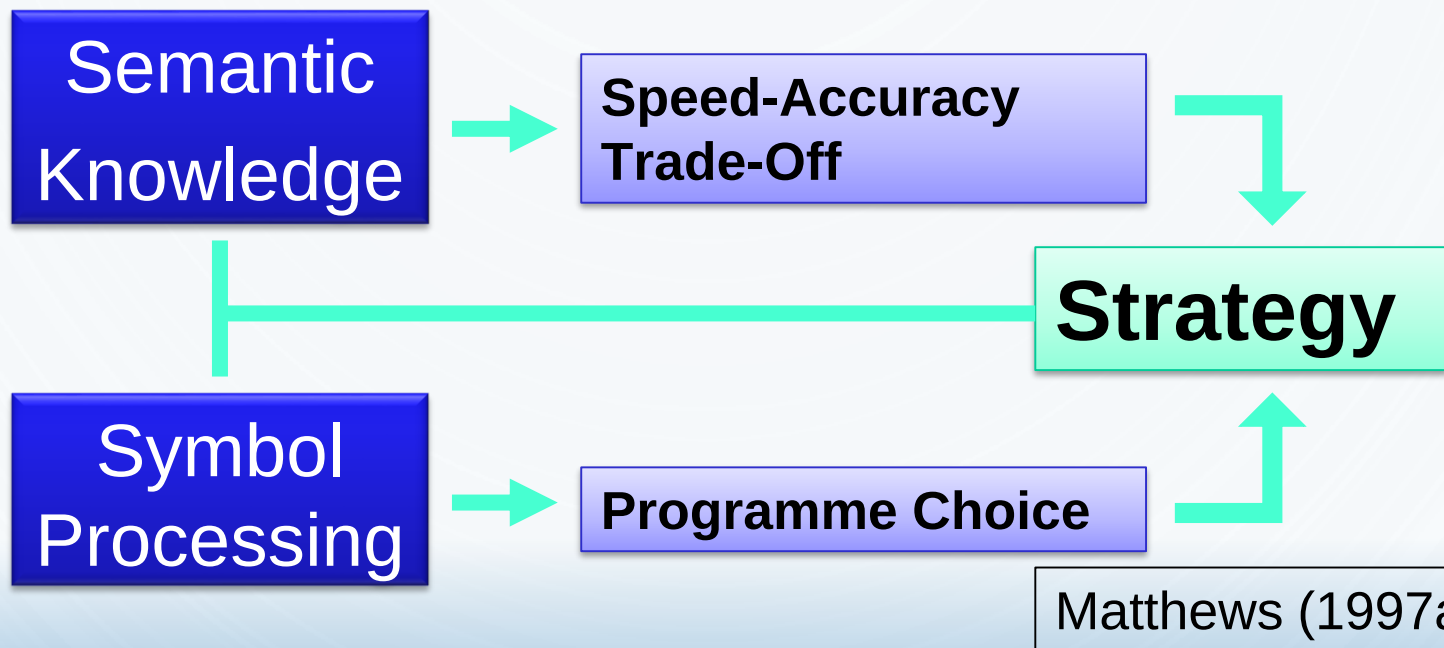
- **Rules to work something out might be the same for everyone but our functional architecture may differ**
- **E.g., someone with less working memory capacity may be unable to comprehend a sentence as quickly as someone else.**

Cognition: Levels of description

- **Cognitive models focus on the algorithm level.**
- **Performance psychology adds by taking into account functional architecture – why?**
 - **Concerned with real-time computations that enable us to perform.**
- **Performance psychology also takes into account semantic/knowledge level.**
 - **Because performing in the real world requires insight into our aims about what we want to do.**

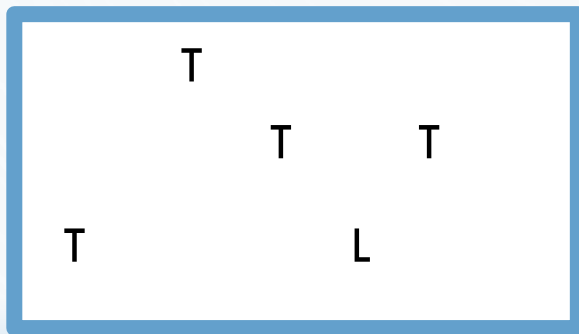
Cognition: Levels of description

- Knowledge & symbol levels link using concept of **strategy**.
 - But: this is influenced by **speed-accuracy trade-off**.
- Symbol level: strategy = alternative programmes to perform a particular task.
 - E.g., programme of a cautious vs. reckless driver.

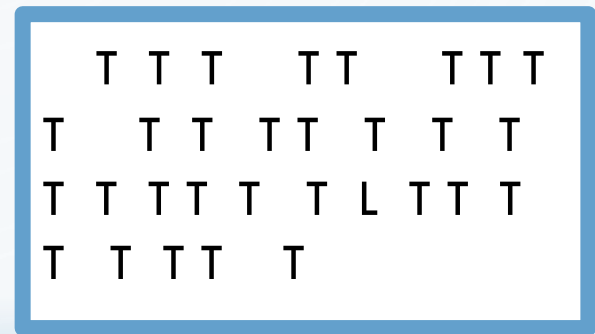


Cognitive Modelling

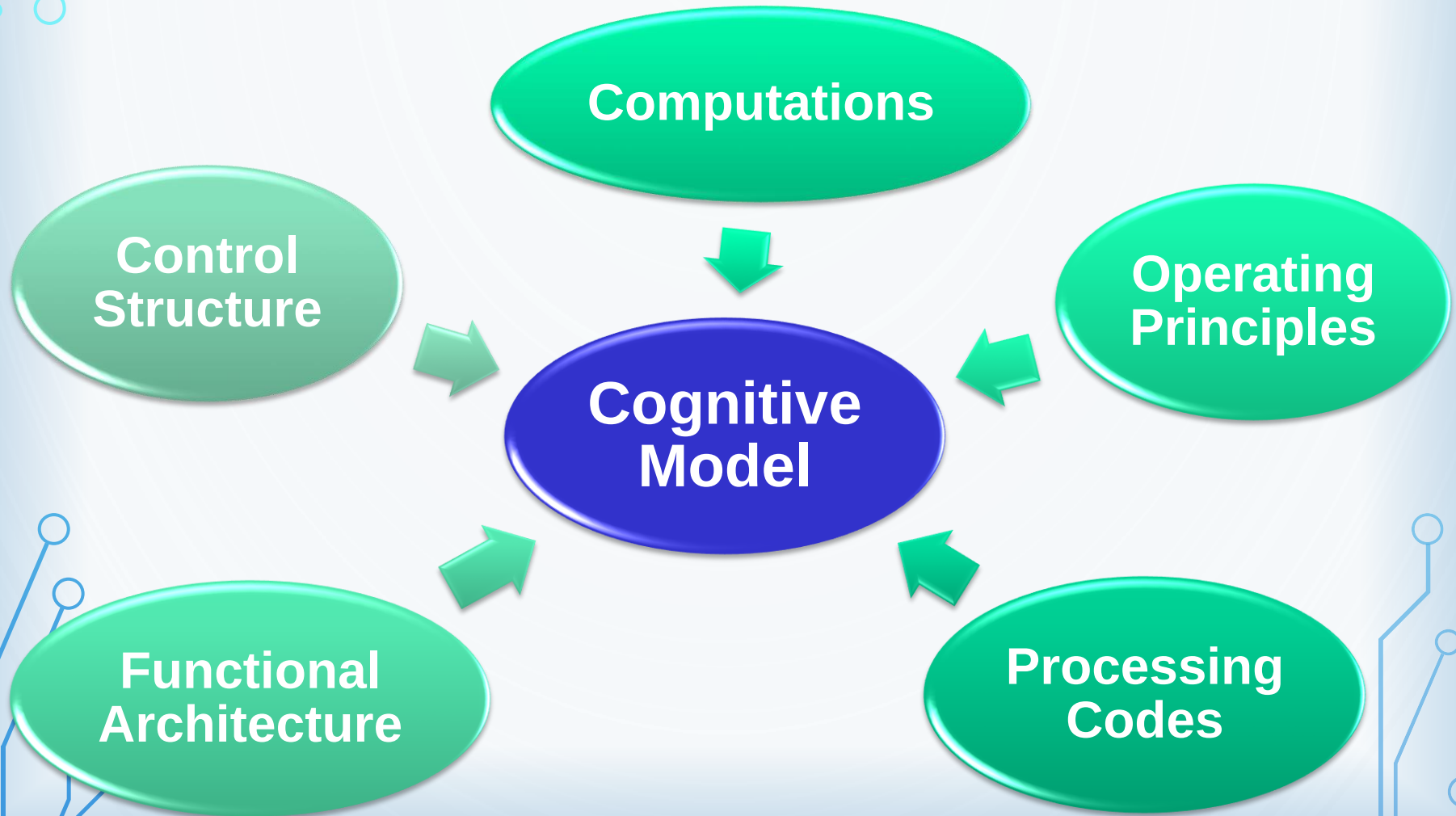
- Explain variations in performance on one type of task.
- However, many different ways to explain performance so different programs can result in the same output.
- Known as the **identification problem** (Anderson)
 - No solution - but models can attempt to explain performance on several different versions of a task.
 - E.g., letter searching tasks use reaction time models.



VS.



How are Cognitive Models built?



Processing Codes

Code	Description
Visual	Properties from stimuli such as their colour, shape, and brightness that are seen through visual perception.
Spatial	Stimulus properties relating to spatial relationships or configuration.
Acoustic	Properties derived from auditory perception: e.g., pitch, intensity, direction of sound.
Phonological	Speech sounds
Lexical	Enters words into our internal dictionary
Semantic	Meaning assigned to the stimulus
Graphemes	Used for spelling and writing
Motor	Instructions sent to muscles to make us move
Articulatory	Instructions sent to larynx to produce speech

Investigating Processing Codes

- Codes can be further broken down.
- Ps required to indicate whether 2 letters were the same.



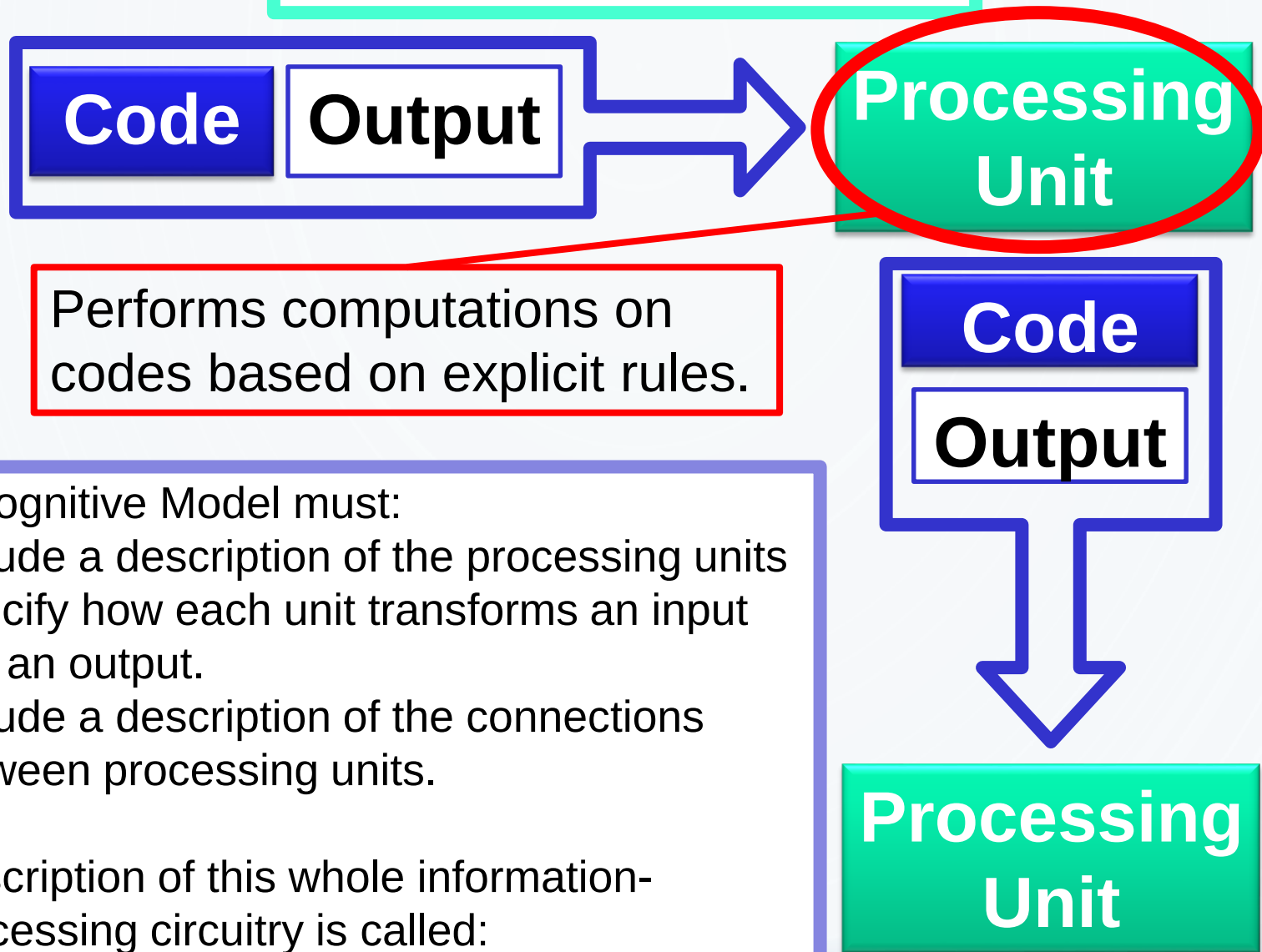
- When letters were the same, the response was faster if they were both in the same case than in different cases.
- Same semantic code but different physical form.

Posner (1978)

Computations

- **Once internal processing codes are defined, what happens with these codes is defined.**
- **Computations on codes are achieved by processing units or component processes.**
- **Processing unit = anything that processes or performs various operations on codes according to predetermined rules.**
 - **Unit then sends a different output code, which is then sent to another processing unit and so on until it results in an output.**

Computations



Performs computations on codes based on explicit rules.

Any Cognitive Model must:

- Include a description of the processing units
- Specify how each unit transforms an input into an output.
- Include a description of the connections between processing units.
- Description of this whole information-processing circuitry is called:

The Cognitive Architecture.

Control Structure

TOP-DOWN PROCESSING

Relies on prior knowledge

Selects/compares
features

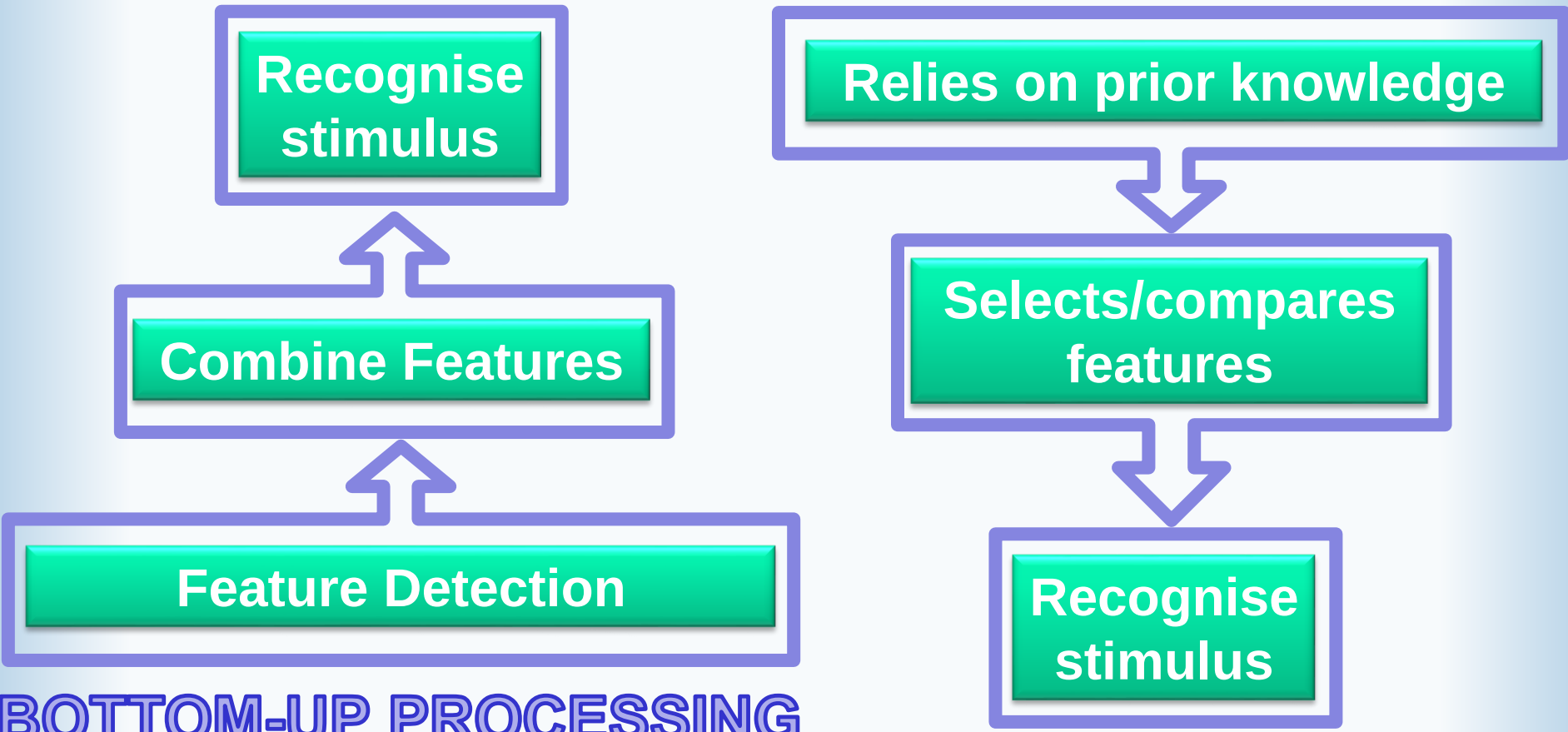
Recognise
stimulus

Recognise
stimulus

Combine Features

Feature Detection

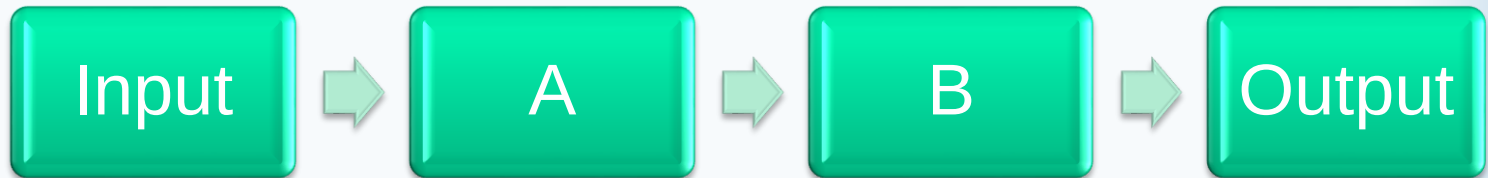
BOTTOM-UP PROCESSING



Control Structure

The “Programming” that controls when a processor will operate

Serial



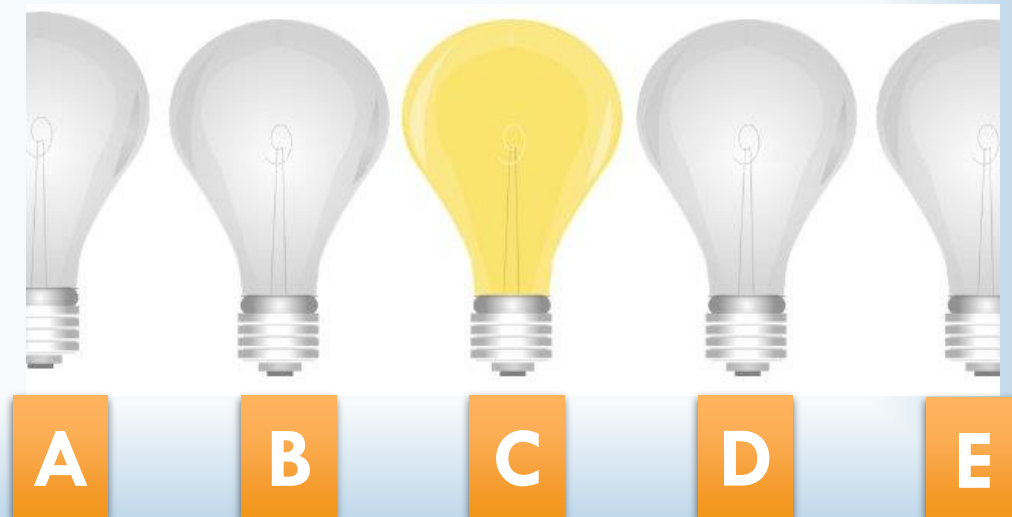
VS.

Parallel



Choice Reaction Time (CRT)

- Performance depends on how **well** and how **rapidly** we choose between options.
 - What cognitive factors should be considered?.....
- Difficult to answer: How can we work out all processes involved, especially when factors in real-life vary?
- **Choice-reaction time (CRT)** tasks help make the decision process explicit.
- E.g., key press choice when light comes on
- Shows speed in which position of light is encoded and speed correct response is made.

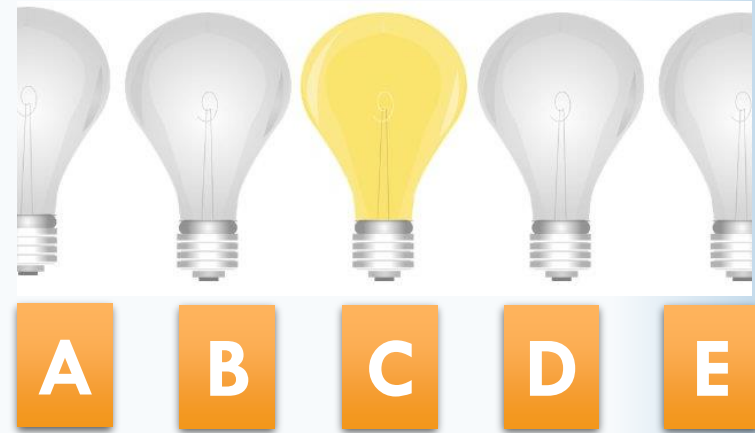


Choice Reaction Time (CRT)

- Two paradigms in which CRT modelling is based:
 - Two-choice
 - Multiple alternative
 - (also called more than 2-choice; $N > 2$).
- Models use statistical or mathematical equations to explain and calculate CRT.
- Modelling achieved through series of stages of processes:
 1. Code for position of light,
 2. Accessing the code for correct response,
 3. Transmission of code to muscles to move correct finger to respond.

Choice Reaction Time (CRT)

- This is a serial processing model.
- But before we can look at how this modelling is achieved we need to understand information theories that attempt to account for CRT.
- What happens to reaction time as the number of choices increases?
 - It becomes slower
 - This was one of the premises that early CRT models were based upon.

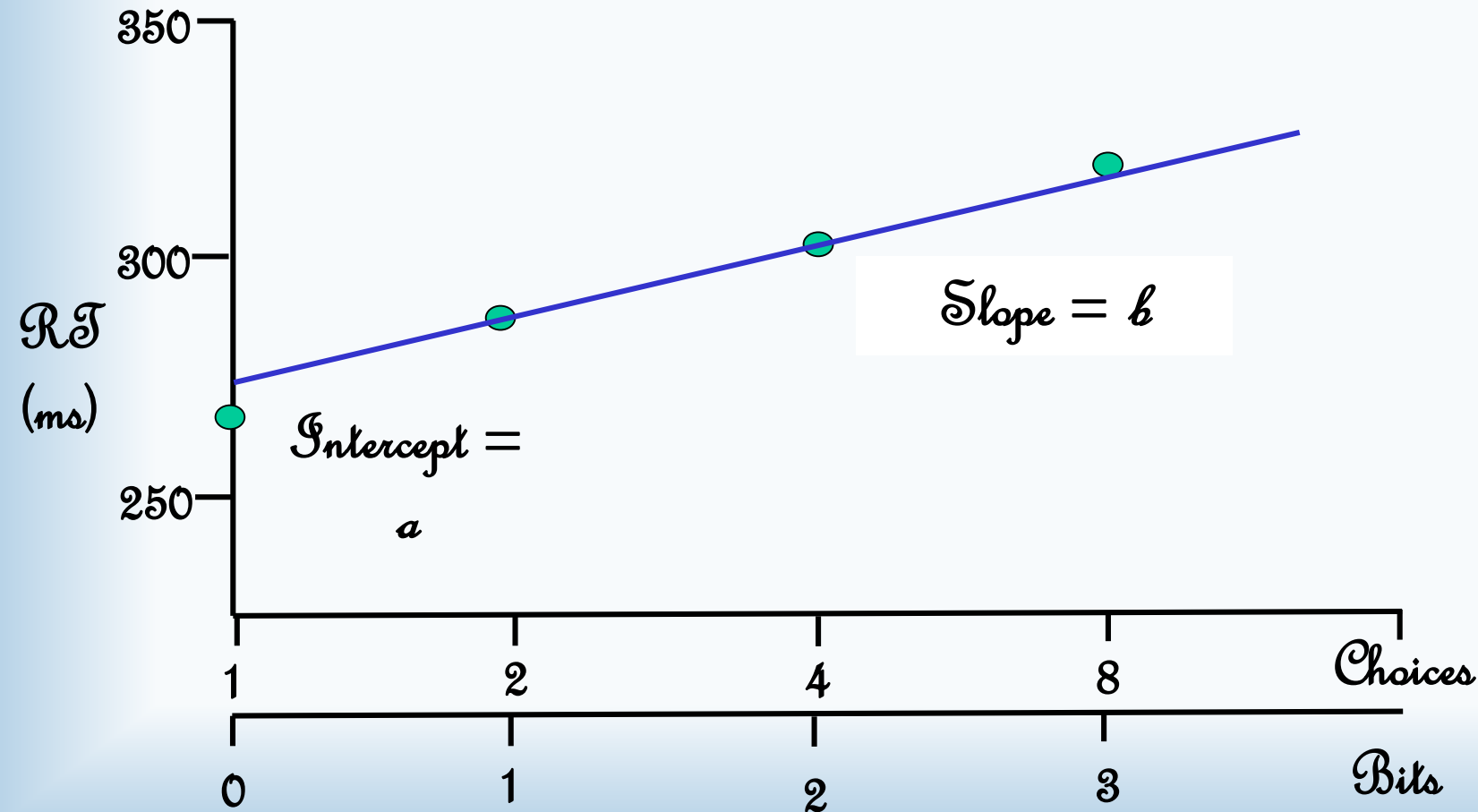


Choice Reaction Time Theories

- Early CRT models used **information-theory** (Shannon & Weaver, 1948).
- Calculated using binary digits (bits), either 0 or 1.
- E.g., choice between 2 items use 1 bit to register info (4 items would use 2 bits, and so on).
- Let's look back at our light and key press study.....
 - As soon as light comes on key decision must be made.
 - Decision will be complicated by number of bits associated with task, so 0 for simple reaction, 1 bit for 2 choices, 2 bits for 4 choices and so on.
- If plotted on a chart, what relationship would it show?

Hick's law

- Any model would predict reaction time should be linearly related to the number of bits of information.
- Mathematically we can work out reaction time through the formula $a + b$ of bits or number of choices.



Choice-Reaction Time Models

- Why are CRT models useful?
- Account for lots of behavioural data.
- Account for lots of experimental paradigms.
- Apply to practical domains – e.g., driving.
- Applied to neurophysiological data to bridge the biological and cognitive domains.

Examples of choice-reaction test at:

<http://www.cambridgecognition.com/tests/choice-reaction-time-crt>

http://www.cogtest.com/tests/cognitive_int/crtflash1.html

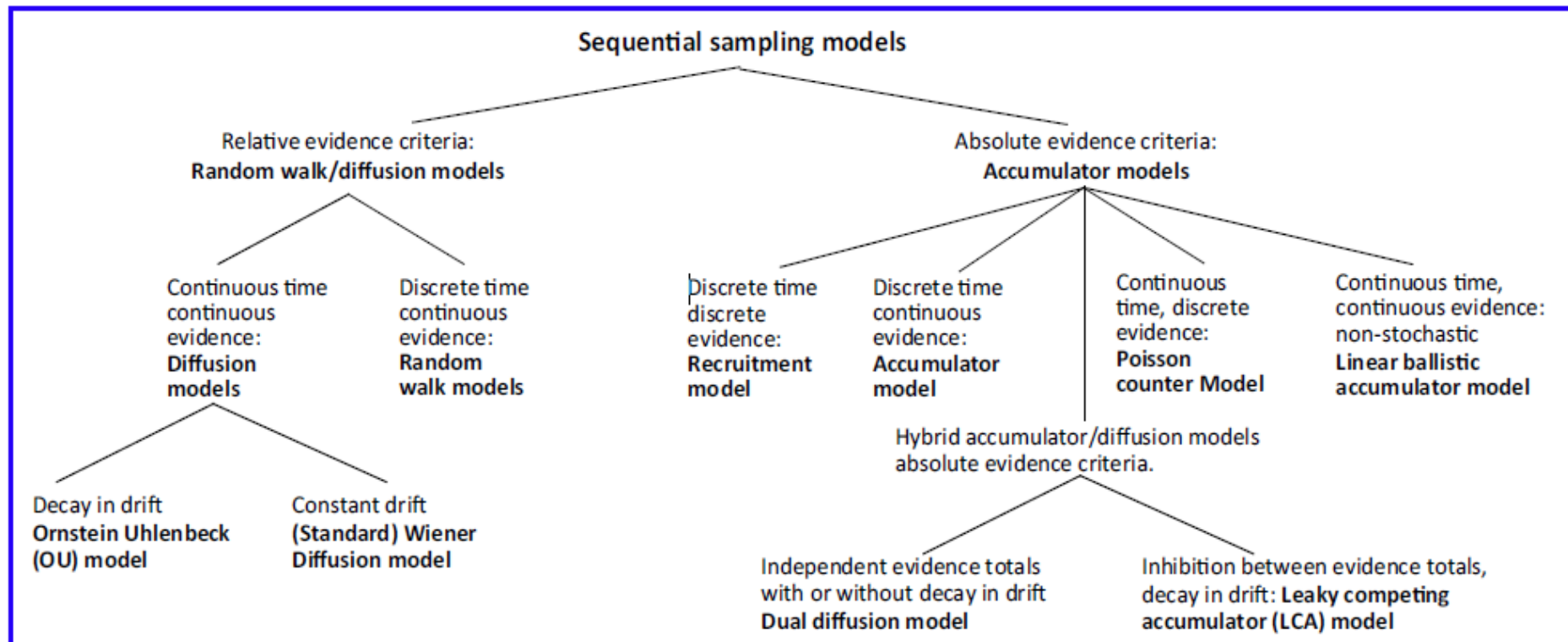
http://www.psychtoolkit.org/lessons/experiment_simple_choice_rts.html

Choice-Reaction Time Models

Chart depicting various models proposed to represent the cognitive and neural processes of choice-reaction time (CRT)

Key Figure From Ratcliff et al. (2016)

Sequential Sampling Models



Choice-Reaction Time Models

Ratcliff, R., Smith, P. L., Brown, S. D., & McKoon, G. (2016). Diffusion Decision Model: Current Issues and History. Trends in cognitive sciences, 20(4), 260-281

- Good paper for overview and includes dialogue boxes (glossary of terms, advantages of diffusion models, and links to real-life applications).
- Includes extensive reference list – strongly recommend using this as basis for further reading.
- They reference previous papers linking models of CRT with: aging, IQ, reading, Schizophrenia, ADHD, driving, etc.

Application of CRT

Two types of application to real-life:

General Behaviour	Clinical Application
Language	Dementia
Bilingualism	Anxiety
Driving	Depression
Intelligence	ADHD
Numeracy ability	ASD
Use of technology	Schizophrenia
Economics	Aphasia
Consumerism	Dyslexia
Reading	Alzheimer's
Sport/Exercise	
Clinical Decision Making	
Aging	

Issues with information theory for CRT modelling

1. Oversimplified:

- Not every choice will be the same:
 - Similarity/discriminability between choice options.
 - Method of response (press button/vocalise?)

2. Does not account for how compatibility between choice and response can affect reaction time.

- E.g., turning wheel on car vs. boat to change direction.

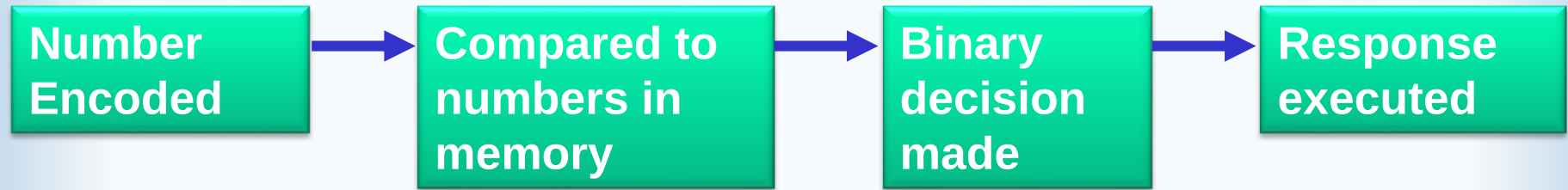
3. Does not account for effects of practice.

Replacement of information theory

- First attempt to measure processes contributing to RT was **subtraction method** (Donders, 1868).
 - Choice reaction is slower than simple reaction, so the difference between them provides the latency of response-choice process.
 - Latency = time between/interval between two things.
- But, not clear whether it involves a single mental operation.
- So, Sternberg (1969) used memory scanning task to work out cognitive processes involved in reaction time.
- Ps presented with list of numbers & state whether target number was presented in list.

Memory scanning task

- Thought to involve 4 serial stages:



- Then implement variable only influencing one of the stages.
- Size of set does not effect encoding, decision, or response.
- But time to compare number with all those in memory will increase with the increase in amount of original numbers.
- Technique is called **Additive Factors** and uses an **Exhaustive search model**: even if match is found, comparison process continues through the set before decision stage comes in to operation.

Issues with Additive factors and serial stage models

1. Difficult to apply in practice: how do we know a particular factor only influences one stage?
2. Are representational codes at each stage continuous or discrete? Is there flow to the next stage before the previous one is complete?
3. Does account for role of person.
 - Are they focusing on choice or speed?
 - **The speed-accuracy trade-off**
 - Each stage may have its own speed accuracy trade off characteristic.
4. Only valid when no time pressure

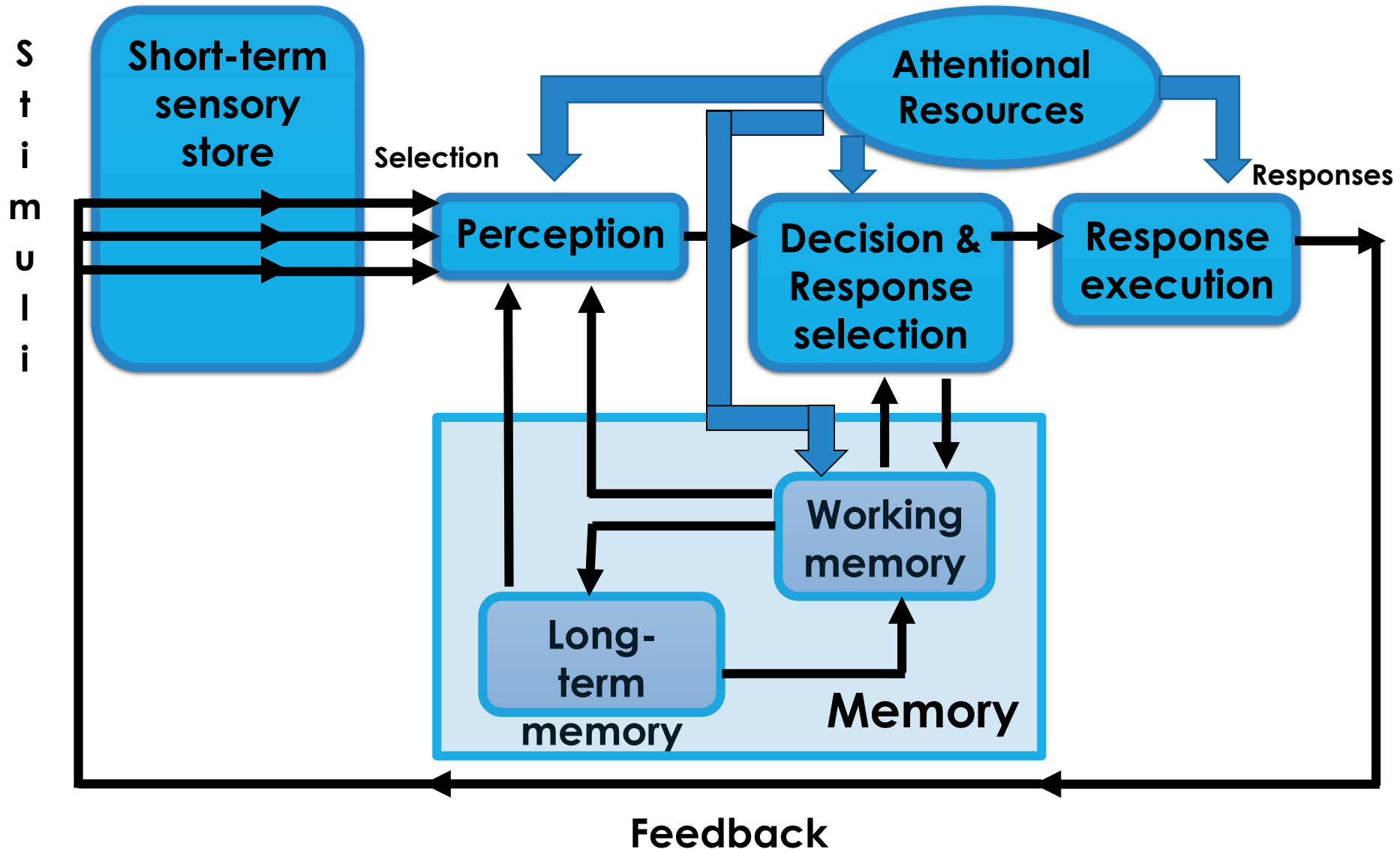
Cognitive Modelling

- Models differ in assumptions about:
 - Representation (symbolic or distributed).
 - Domain-specificity and modularity.
 - Need for & nature of built-in (innate) constraints
- Important to consider extent cognitive abilities are determined by physical body and environment.
- If data do not conform to model should we reject it?
- Underlying principles may be correct but fails due to minor problem in programming.
- We should develop and refine models to account for any new seemingly conflicting data (Newall).

INFORMATION-PROCESSING

- Models of information processing provide useful frameworks for analysing different psychological processes used when we perform and carry out tasks.
- These models depict a series of processing stages or mental operations that usually characterise the flow of information as a human performs a task.
- However, the suggestion of serial processing is challenged by findings suggesting parallel processing occurs.
- Also, modelling for higher order cognitive functioning is complex and somewhat lags behind.

A structure for Information-processing (Wickens, 1992)



Parallel Processing models

Spreading Activation Models

FISH

+

CHIPS

Concerned with structure of LTM & the way information is retrieved from it to make decisions about concepts.

3 Principles of Association:

- **Contiguity** (association through occurrence in time).
- **Similarity** (associated because they are alike).
- **Contrast** (associated because they are opposite).

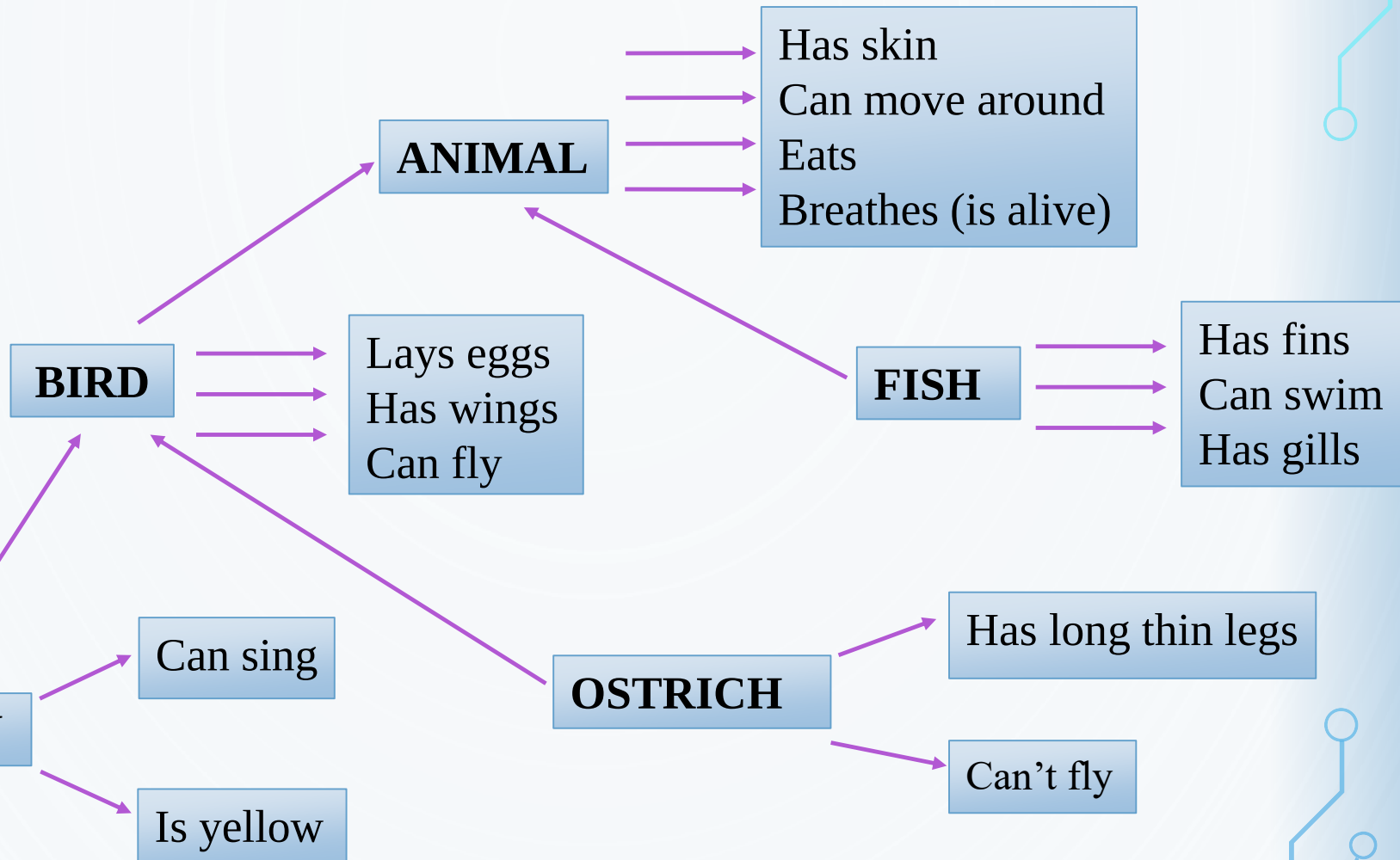
Can you think of any real-life examples that fit these three principles?

Parallel Processing models

Spreading Activation Models

- Make two types of statements:
 1. Describes hierarchical structure of concept associations.
 2. Describes the spreading activation.
- Each concept has an activation value, which is low or zero.
- Experience activates corresponding concepts.
- Activation spreads to associated concepts (decays over time).
- Activation to a threshold level may not be great enough to reach conscious awareness.
- Rate of spread reflects strength of associated link (determined by factors such as similarity of concepts).

Spreading Activation Models



Collins & Quillian (1969)

TESTING SPREADING ACTIVATION MODELS

Two methods:

1. Sentence verification

- Answer “true” or “false” to questions: e.g., “is a canary a bird?”
- Length of response time depends on time taken to activate spread from “canary” to “bird”.
- As number of associative links increases, RT becomes longer.

2. Priming:

- Commonly used task = Lexical decision (Meyer & Schvaneveldt, 1972)
 - Decide whether or not a string of letters is a valid word.

Valid Trial

CAR
HOUSE
TABLE
NURSE

Valid Trial (Priming)

TABLE
NURSE
DOCTOR
HOUSE

Invalid Trial

BSDLW
TNEUP
RETCA
EHRTO

SPREADING ACTIVATION MODELS: EVALUATION

Shows how information can be processed in parallel and is suitable at explaining outcomes from experimental research.

However, some issues are highlighted:

1. Eleanor Rosch (1973): RT depends on typicality of concepts:
 - Certain instances/objects within a particular category can look more typical of that category than others
 - e.g., pigeon processed faster than penguin as a bird, despite both being categorised birds.



BIRD



SPREADING ACTIVATION MODELS: EVALUATION

2. Knowledge organised in a hierarchy???

- People have different experiences so links not the same.

3. Control of processing is bottom-up: model needs to account for strategies involving us searching for information (top-down).

4. Data from priming studies may not be supportive.

- Different mechanisms explain priming.
- Neely (1991): the model fits priming when the time between seeing the prime and seeing the target word is less than 300 milliseconds or when non-words resemble actual words.
 - When non-words look like actual words the RT to actual words are influenced by a checking procedure.

5. In general the model is oversimplified.

Parallel Processing models

2. Connectionist Models

- Explains range of cognitive phenomenon
- Concern with learning responses through algorithms
- Reject idea of a controlling executive system.
- Make use of representations consistent with physiology:
 - Networks resemble interconnected neurons.
 - Each unit has activation level: an associated level of energy that can be transmitted to other units.
 - Nature of transmission depends on type of connection.
 - Connections have **facilitatory** or **inhibitory** weights.
 - Weights can vary in size and direction

Parallel Processing models

2. Connectionist Models

- Number of rules in the system:
 1. Activation rule: determines way unit deals with input.
 2. Output rule: determines what unit will output to others
 3. Learning rule: determines how weights associated with connections between units are changed.
- All rules thought to be hardwired - contained within physical properties of the system.

CONNECTIONIST MODEL: EXAMPLE

Interactive Activation Model (IAM): McClelland & Rumelhart (1981)

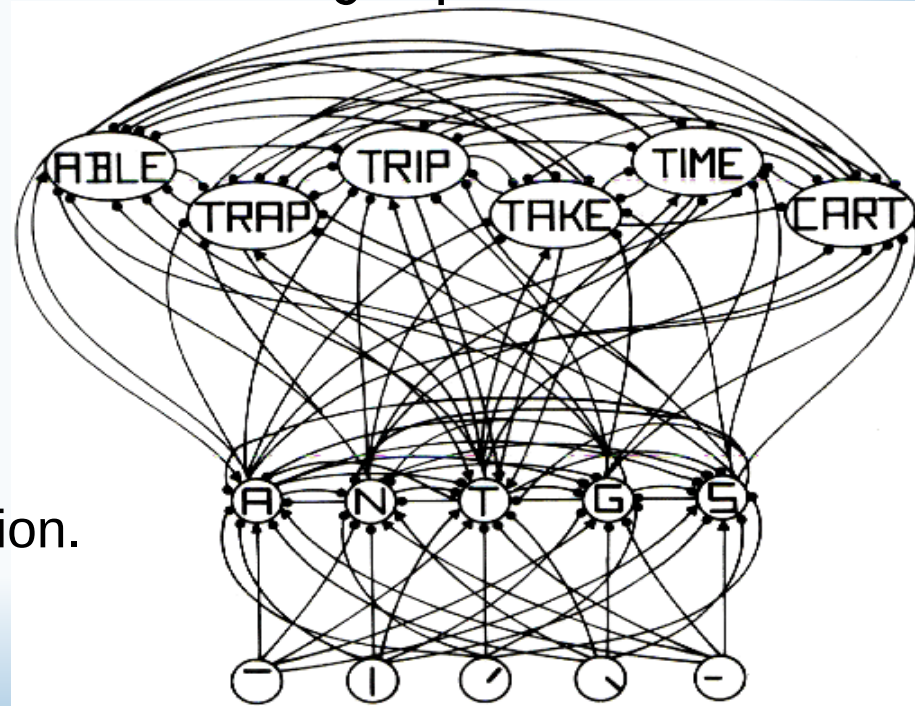
- Attempts to simulate word recognition with units arranged in 3 levels:
- Each level codes for a different type of property:
 1. Activating features: line segments of a letter
 2. Letter representations (bottom-up parallel process).
 3. Word unit (top-down processing also occurs).
- Feature units can inhibit letter units not containing a particular feature.

Nodes:

1. Word detector
2. Letter (Position)
3. Feature (Visual)

Arrows show excitatory connection.

Rounded heads show inhibitory connection.

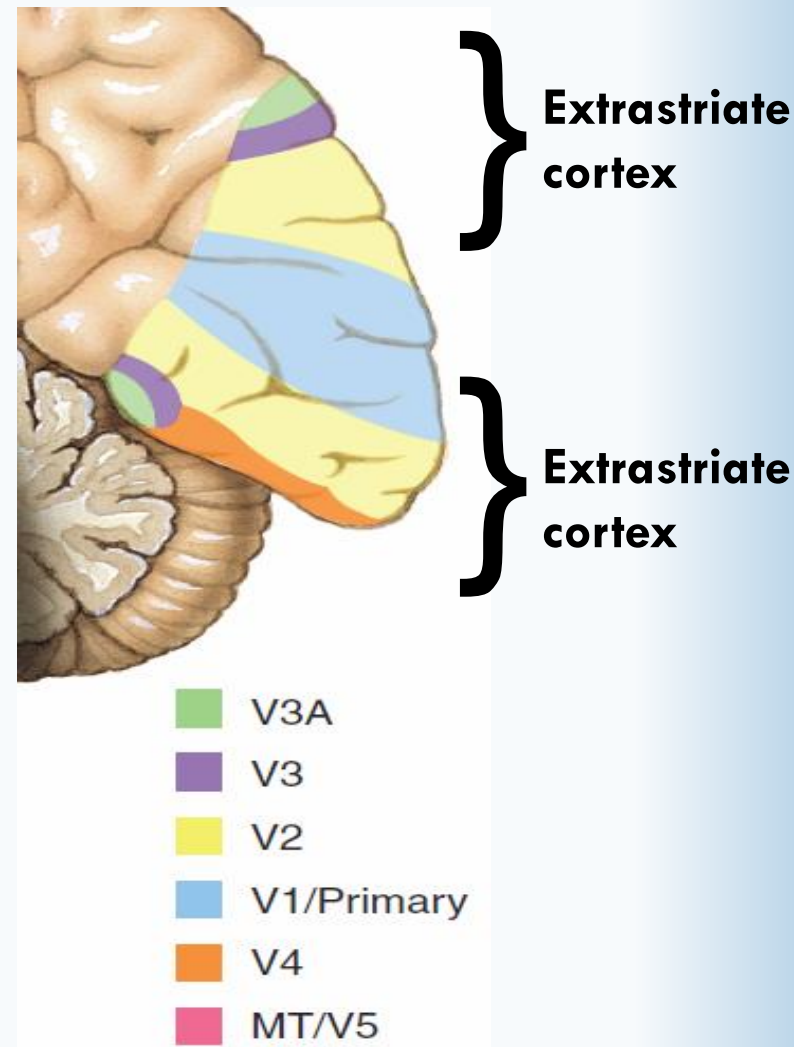


Connectionist Model: Evaluation

- Step-up from spreading activation models.
- However, criticised for not representing formal structure of inter-relationships between mental states.
- Lack explanatory power associated with the symbolic approaches to cognition.
- Only useful for explaining certain things
 - E.g., language acquisition.
- The links it has in intending to copy neural functioning have limited application and are not direct models of neural processing.

Evidence from Cognitive Neurophysiology

- Physical processes of brain & mental processes of mind examined with PET.
 - Aim: investigate cognitions involved in visual word recognition.
 - Findings: increased cortical activity in extra-striate cortex when we passively view word compared to fixation cross.
- But does this tell us anything about cognitive processing?



If area of brain lights up in imaging study does that mean it is processing a physical code or a semantic code?

Evidence from Cognitive Neurophysiology

- Posner & Raichle (1997): Developed exp to show how letters can be represented by physical and semantic codes.
- Suggest 4 processing codes to describe hierarchy of cognitive processing associated with visual word recognition:
 1. Bottom level: visual features of letters recognised (length & direction of lines).
 2. Specific patterns of features conjoined to recognise the letter.
 3. Orthographic recognition (application of the rules of language)
 4. Recognition of semantic content of the word.
- Based on this, they devised 4 different types of visual stimuli.
- Each one intending to map on to the different levels of the processing code hierarchy.
- Ps required to view stimuli passively while cortical activity recorded.

Evidence from Cognitive Neurophysiology

Cognitive Processing Codes

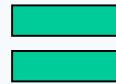
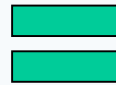
Corresponding visual stimuli

Semantic
Recognition

Orthographic
Recognition

Recognition of
Letter

Recognition of
Visual Features

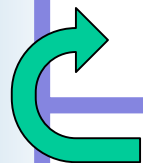


Words
DUST

Pseudo words
ALDOBER

Letter string
VSFFHT

False Fonts
ƆHḡEY



Findings: All were associated with brain activity in visual areas outside primary visual cortex.

- **But only pseudo words & real words produced pattern originally seen when words alone were shown in previous studies.**

Evidence from Cognitive Neurophysiology

- **There must be 2 levels of analysis of visual info occurring in visual system as we passively view words:**
 1. **The brain analyses visual features of stimuli regardless of relationship to letters and words**
 2. **The brain analyses the visual word form, which incorporates orthographic rules of language.**
- **But what do we know about PET that makes it difficult to accept findings at face value?.....**
 - **Too slow to measure speed of information processing**
 - **Not the best way to investigate time-course of cognition**
 - **ERP would be better but then you lose ability to localise the area of activation.**

LECTURE SUMMARY

- **Aim of modelling: to understand cognitive processing**
 - E.g., understand how we make a decision within a specified timeframe when we have multiple choices
 - Choice-reaction time modelling.
 - Do this by attempting to reverse engineer the processing that occurs between input and output.
- **Cognition is described by information processing**
 - Various models proposed – e.g., Spreading activation vs. Connectionist models.

FURTHER READING – KEY JOURNAL ARTICLES

CRT MODELS

- Brown, S. D., & Heathcote, A. (2008). The simplest complete model of choice response time: Linear ballistic accumulation. *Cognitive psychology*, 57(3), 153-178.
- Karalunas, S. L., Geurts, H. M., Konrad, K., Bender, S., & Nigg, J. T. (2014). Annual Research Review: Reaction time variability in ADHD and autism spectrum disorders: measurement and mechanisms of a proposed trans-diagnostic phenotype. *Journal of Child Psychology and Psychiatry*, 55(6), 685-710.
- Ratcliff, R., & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. *Neural computation*, 20(4), 873-922.
- Ratcliff, R., & Smith, P. L. (2004). A comparison of sequential sampling models for two-choice reaction time. *Psychological review*, 111(2), 333.
- Ratcliff, R., & Strayer, D. (2014). Modeling simple driving tasks with a one-boundary diffusion model. *Psychonomic bulletin & review*, 21(3), 577-589.
- Ratcliff, R., Smith, P. L., Brown, S. D., & McKoon, G. (2016). Diffusion Decision Model: Current Issues and History. *Trends in cognitive sciences*, 20(4), 260-281.
- Usher, M., & McClelland, J. L. (2001). The time course of perceptual choice: the leaky, competing accumulator model. *Psychological review*, 108(3), 550.

NEXT WEEK

- Lecture: Artificial Intelligence (AI).
- Seminar: Essay assignment guidance
- ESSENTIAL READING: See module handbook.