

# Computational cognitive neuroscience

*with the Neuroscience of Cognitive Control Lab*

## Talking points

### Knowledge

1. How much power does a human brain use?

### Comprehension

2. What is the difference between a function and an algorithm?
3. How are functions and algorithms used to create computational models?
4. What is the difference between episodic and semantic memories?
5. Why do most processes have a trade-off between flexibility and efficiency?

### Application

6. Other than weather and a human brain, what complex natural phenomenon could be described by a computational model? What variables would be inputs for the model?
7. What are the applications of computational models of human intelligence?

### Analysis

8. How will PsyNeuLink help psychologists, neuroscientists and computer scientists gain a better understanding of human intelligence?

### Synthesis

9. Some tasks that require intelligence have multiple different solutions. How could you discover if a computational model is performing a task in the same way humans, or in a different way?

### Evaluation

10. To what extent do you believe that a human mind can truly be replicated in a computer?

## Activities

### Conduct a cognitive experiment

The Stroop task is an experiment that illustrates the flexibility of cognitive control in humans and allows researchers to explore how it functions. In this task, a person is shown the written name of a colour displayed in a different colour than the word (e.g., **GREEN**). The person is either asked to read the word (i.e., to say 'green') or to name the colour (i.e., to say 'red').

If the person is not instructed on how to respond, their default response will be to read the word, as this is an automatic process that does not require much cognitive control. In contrast, naming the colour requires cognitive control to overcome the default, automatic response of reading the word. However, this is only the case when the word and colour are in conflict (i.e., they are incongruent). If the word and colour match (i.e., they are congruent, e.g., **RED**), or if they are instructed to name the colour of a neutral stimulus (such as a sequence of letters that do not spell a word, e.g., **XYZ**), then people do not have trouble naming the colour.

The contrast in performance between incongruent, congruent and neutral conditions is referred to as the Stroop effect. This can be seen in errors people make (e.g., mistakenly responding with the word when instructed to name the colour) and in the time taken to respond to the stimulus (almost universally, people take 1/10 to 1/5 of a second longer to name the colour when it conflicts with the word). The Stroop effect highlights how a person must engage cognitive control when performing a task (e.g., naming a colour) that conflicts with a more automatic task (e.g., reading a word).

Conduct an experiment to explore how your classmates respond to the Stroop task. First, create two word-cards, each containing 25 colour names. On one word-card, write each name in the correct colour (e.g., **RED**, **GREEN**, **BLUE**, **BLACK**, **GREEN**, **PURPLE**...); this is the congruent condition. On

**YELLOW RED PURPLE**  
**BLACK RED ORANGE**  
**PURPLE BLACK BLUE**  
**BLUE GREEN YELLOW RED**  
**YELLOW BLACK GREEN**  
**BLUE PURPLE BLACK**  
**RED GREEN RED ORANGE**  
**BLACK YELLOW PURPLE**

the second word-card, write each name in a different colour (e.g., **RED**, **GREEN**, **BLUE**, **BLACK**, **GREEN**, **PURPLE**...); this is the incongruent (or conflict) condition.

In your experiment, you will time people as they read the words on the congruent card and then as they say the colours on the incongruent card. Before you begin, write a hypothesis about how you expect people will perform in each task.

Conduct your experiment with one participant at a time. Give them the congruent card, face down, and explain that you want them to read the words on the card as quickly and accurately as possible. Ask them to turn over the card and start reading and, at the same time, start a stopwatch to time them. Record how long it takes them to read the 25 words. Then, give them the incongruent card, face down, and explain that you want them to say the names of the colour each word is written in as quickly and accurately as possible. Ask them to turn over the card and start naming the colours and, at the same time, start timing them. Record how long it takes them to name the 25 colours.

During each task, you should also record all errors the participants make. You may find it challenging to keep track as they perform the task. What does this tell you about your capacity for control?

When all your participants have completed the experiment, analyse and interpret your results. For example, what were the average times taken for

each card? What do your results indicate about how the human brain processes different types of visual information?

Consider how you could alter this experiment to explore different aspects of cognition. For example, how could you adjust the Stroop task to test cognitive flexibility in someone who is colourblind or partially sighted? What do you think would happen to the time difference in responding to the two word-cards if the colour names were written in a different language? For example, read the words in Spanish (**ROJO**, **VERDE**, **AZUL**, **NEGRO**, **VERDE**, **MORADO**...) but name the colours in English.

### Build your own computational model

There are many free online platforms that allow you to build your own simplified computational models of dynamic systems and explore how feedback loops impact different variables within the systems. Loopy ([www.ncase.me/loopy](http://www.ncase.me/loopy)) and SageModeler ([sagemodeler.concord.org](http://sagemodeler.concord.org)) are good places to start.

For example, can you build a computational model of a food web? If rabbits and mice eat grass, foxes and hawks eat rabbits and mice, and owls eat mice, what would happen to the system if the number of foxes decreased?

### A computational model for picking berries

A computational model of cognitive control when picking berries can be built from simple elements: a task, a set of stimuli [ripe berry, unripe berry, bee] and a set of responses [pick, avoid]. Values are assigned to a reward/punishment matrix of stimulus-response combinations to indicate the outcome of different responses to different stimuli.

**Task 1** is to pick as many ripe berries as efficiently as possible without getting stung by bees. The reward/punishment matrix is: picking a ripe berry = +3; picking an unripe berry = -1 (it has a bitter taste and you wasted effort collecting it); picking a bee = -30 (you get hurt).

**Task 2** is to pick unripe berries to place in a jar to ripen later. Placing a ripe berry in the jar will cause all the berries to spoil, so the reward/punishment matrix changes to: picking a ripe berry = -10; picking an unripe berry = +3; picking a bee = -30.

This cognitive challenge could be programmed into a video game so psychologists could collect behavioural data on how people respond to the tasks and learn to adapt as they switch between them. Patterns in the behavioural data could reveal what strategies, trade-offs and difficulties humans face when performing and switching between the two tasks.

### Questions:

1. If you need to perform both tasks on a single berry bush, what is the optimal approach?
2. What would your learning trajectory look like if you did Task 1 for an hour, then suddenly switched to Task 2?
3. What would happen to your picking efficiency if you had to switch between the tasks every 20 seconds?

## More resources

- Read about the research being conducted by the Neuroscience of Cognitive Control Lab: [ncclab.princeton.edu](http://ncclab.princeton.edu)
- Visit the team's Futurum webpage to download a PowerPoint about creating computational models of human intelligence: [www.futurumcareers.com/modelling-minds](http://www.futurumcareers.com/modelling-minds)
- Learn more about how humans apply past knowledge to new situations, and how it can help your learning: [www.habitsofmindinstitute.org/applying-past-knowledge-to-new-situations](http://www.habitsofmindinstitute.org/applying-past-knowledge-to-new-situations)