Neuromorphic Cognitive Computing and Brain-Like Intelligence

神经形态认知计算与类脑智能

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Neuromorphic Computing

Brain’s Computing Machinery

The brain works by neurons communicating via synapses

2013 Nobel Prize in Physiology or Medicine

Brain’s ‘Inner GPS’

Brain’s positioning system: Cognitive Map

2014 Nobel Prize in Physiology or Medicine

Places where grid cell fires

Bright areas
What is cognitive computing?

- Cognitive computing aims to develop a coherent, unified, universal mechanism inspired by the mind’s capabilities. [IBM, 2011]
- It is computing based on neuromorphic architecture and explores various processes including sensation, perception, action, emotion, and cognition.
Cognitive Computing

• It integrates ambiguous sensor information from sight, hearing, touch, taste, and smell; it can form spatiotemporal associations and abstract concepts; it can make decisions and initiate sophisticated coordinated actions.

• Cross-disciplinary.
Cognitive Computing

- The human brain—the world's most sophisticated computer can perform complex tasks rapidly and accurately using the same amount of energy as a 20W light bulb in a space equivalent to a 2L water bottle.

- Make brainy computers that think like a human, by using advanced algorithms and silicon circuitry.
Brain’s Cognitive Mechanism

2014 Nobel Prize in Physiology or Medicine

John O’Keefe, May-Britt Moser, and Edvard I. Moser

Brain’s positioning system: Cognitive Map

“The contribution that the three Noble laureates have made to this field represents a huge step forward in our understanding of how groups of specialized cells work together to execute higher cognitive functions, such as memory, thinking and planning.”
Place cells

The hippocampus, where the place cells are located is highlighted. The grey square depicts the open field the rat is moving over. Place cells fire when the animal reaches a particular location in the environment. The dots indicate the rat’s location in the arena when the place cell is active. Different place cells in the hippocampus fire at different places in the arena.

http://www.nobelprize.org/nobel_prizes/medicine/laureates/2014/
Place cells

Box

Hippocampal Place Fields

Circular Track

http://krieger.jhu.edu/mbi/knierimlab/research/index.html
The grid cells are located in the entorhinal cortex depicted in blue. A single grid cell fires when the animal reaches particular locations in the arena. These locations are arranged in a hexagonal pattern.

http://www.nobelprize.org/nobel_prizes/medicine/laureates/2014/
Grid Cells

Grid cell in the entorhinal cortex. Left: Trajectory of the rat (black) with spike locations superimposed (red). Right: Colour-coded map showing firing rate distribution for the same cell. The colour scale is from blue (silent) to red (peak rate).

http://www.scholarpedia.org/article/Grid_cells
Properties of Grid Cells

1. Spatially stable, regular hexagonal firing
2. Local grids tile environment (random offset)
3. Spacing increases at more ventral locations
4. Code comprised of different scales is sufficient to localize the rat

Grid Cells for Path Integration

Grid Cell firing patterns in a module code movement distance and direction

When animal is on a bump of Grid Cell A and moves a particular distance and direction, Grid Cells B and C will fire.

firing: A → B → C

= from position A move SW a certain distance

http://blog.brainfacts.org/2013/08/human-grid-cells/
From Grid Cells to Place Cells

http://www.nobelprize.org/nobel_prizes/medicine/laureates/2014/

What and Where: A unified cognitive system

“WHAT”

Nonspatial Information

perirhinal

LEC

dentate gyrus

CA3

“WHERE”

Spatial Information

postrhinal

MEC

CA1 distal

CA1 proximal

http://krieger.jhu.edu/mbi/knierimlab/research/index.html
Our Computational Model

Visual Calibration

(3) Place Cells

Grid Cells

(1) Self-Motion (Raw Odometry)

(2) Resetting

Path Integration

(4) Cognitive Map
A Robot Finds Its Way Using Artificial “GPS” Brain Cells

One robot has been given a simulated version of the brain cells that let animals build a mental map of their surroundings.

by Will Knight    October 19, 2015

Publication:
An Entorhinal-Hippocampal Model for Simultaneous Cognitive Map Building.
In: Proceedings of the 29th AAAI Conference on Artificial Intelligence (AAAI-15), Austin, TX, USA, 2015. [Oral Presentation (rate 11.75%)]
Loop Closure Detection & Resetting

(a) t=15s
(b) t=265s
(c) t=267.5s

(d) 10 20 30 40
(e) 10 20 30 40
(f) 10 20 30 40

(g) 10 20 30 40
(h) 10 20 30 40
(i) 10 20 30 40
Two Indoor Environments
Map Building and Neural Responses

- **Raw map**
- **Cognitive map**
- **Neural responses**
- **Rate map**

![Graphs and charts illustrating different data representations related to map building and neural responses.](image-url)
Acknowledgements

类脑计算研究中心网址:
http://ncrc.scu.edu.cn
Thank You!