PSYCO 403

Week 7: Examples Of The Cognitive Sciences

The Disembodied Mind
Reorienting With Disembodied Modules
The Brain as Body
Reorienting With Networks
Embodied Robots
Sense-Act Reorientation

Navigation Case Study

- Navigation is a fundamental ability that permits agents to adapt to their world
- We are going to consider one particular aspect of navigation, reorientation, as a case study
- This is because reorientation has led to theories in three different traditions of cognitive science: classical, connectionist, and embodied
- We will consider each of these types of theories in turn

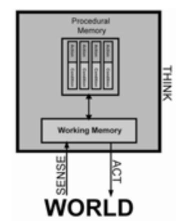
The Western Self

- Western thought has a deeply entrenched distinction between the mind and body, or between the self and the world
- "The division [between mind and body] is so deep-seated that it has affected even our language. We have no word by which to name mind-body in a unified wholeness of operation" (John Dewey, 1928)
- This division is rooted in the Cartesian philosophy that inspired classical cognitive science

John Dewey

Cognitivism and Disembodiment

- Cartesian disembodiment is a central, tacit assumption of symbolic or classical cognitive science
- The mind works by using inputs to build a model of the world, and uses this model to plan action
- Sense-think-act cycle
- Hurley's "classical sandwich"

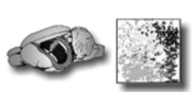


Susan Hurley

Navigation Example: Cognitive Map

- "The stimuli which are allowed in are not connected by just simple one-to-one switches to the outgoing responses. Rather the incoming impulses are usually worked over and elaborated in the central control room into a tentative cognitive-like map of the environment. And it is this tentative map, indicating routes and paths and environmental relationships, which finally determines what responses, if any, the animal will finally make." (Tolman, 1948, p192)

Edward C. Tolman



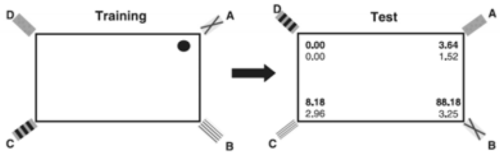
Place cells in the hippocampus as the cognitive map

The Reorientation Task

- One aspect of navigation is studied by using the reorientation task
  - Find a reinforced location in an arena
  - Use geometric information (shape)
  - Use local information (wall color, landmarks)
  - Later, reorient one's self to the goal location when placed in new arena
- How is this accomplished? What cues are used? What happens when geometric and local cues conflict?
- One approach to answering these questions is very classical in nature

Affine Transformation

- When landmarks are rotated, this is equivalent to an affine transformation of the entire shape of the arena. How will the agent reorient – will it use the landmarks alone?



Rotational Error

- Geometric cues on their own are ambiguous
- Rotational error: go to A and C mostly and equally, and rarely go to B or D
- Rotational error is often viewed as evidence of geometric cues being processed by a geometric module

Figure 1 *Schematic representation of the geometrical information which is available in a rectangular-shaped environment. The target (filled dot) stands in the same geometric relation to the shape of the environment as its rotational equivalent (open dot). Metric information (i.e. distinction between a short and a long wall) together with sense (i.e. distinction between left and right) suffices to distinguish between locations A-C and locations B-D, but not to distinguish between A and C (or between B and D).*

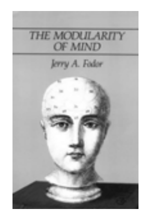
Modules And Isotropic Processes

- A module is a system that is isolated from others, has strong biological ties, and is used to solve a specific information processing problem
- A module is the opposite of an isotropic system, which is a general purpose problem solver, must have access to any relevant information

Jerry Fodor

Properties Of Modules

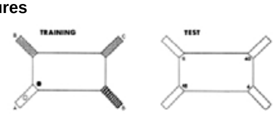
- What are the properties of modules?
  - Rapid processing
  - Mandatory action
  - Domain specific
  - Run to completion
  - Informationally encapsulated
  - Characteristic breakdown
- Why do modules have such properties?
  - They are wired directly into the brain to solve specific information processing problems – they are part of the architecture!



Geometric Representation

- Rotational error is often explained classically by appealing to geometric representations
  - "One unit of the mind, which I will call the metric frame, encodes only the geometric properties in the arrangement of surfaces as surfaces. It encodes the shape of the environment, including the displacement properties in that shape" (Cheng, 1986)
- These representations are further thought to be modular, because rotational error appears even when task can be solved by local features alone
- Processing of arena shape is mandatory action of geometric module!

Ken Cheng



SLAM: The Thinking Navigator

- To explain reorientation, and rotational error, by appealing to a geometric module is an example of exploiting disembodied sense-think-act processing
- Gallistel (1990, p. 121) notes "orienting towards points in the environment by virtue of the position the point occupies in the larger environmental framework is the rule rather than the exception and, thus, cognitive maps are ubiquitous."
- Similar accounts for robots, such as SLAM (simultaneous localization and mapping), are common
- "Low level robots may function quite adequately in their environment using simple reactive behaviors and random exploration, but more advanced capabilities require some type of mapping and navigation system" (Milford, 2008, p. 10).

Randy Gallistel

Michael Milford

Against The Disembodied

- Classical cognitive science, with its tacit views of disembodiment and logicism, is comfortable with the notion of mind as “software” running on a computer
- Connectionism has reacted strongly against this view
- “These dissimilarities do not imply that brains are not computers, but only that brains are not serial digital computers” (Churchland, Koch & Sejnowski, 1990)
- Connectionists take the embodiment of the brain seriously

Patricia Churchland

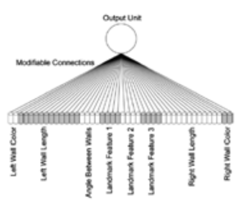
Connectionist Cognitive Science

- Connectionism can be viewed as a perspective on mind that abandons Descartes, and instead accepts Locke
- “No man's knowledge here can go beyond his experience”
- Artificial neural networks are viewed as blank, neuronally inspired, slates that can be shaped by the environment
- The result is a messy, distributed set of pattern recognizing associations compatible with the brain, and incompatible with logicism

John Locke

A Reorienting Network

- Connectionism has been used to explore the reorientation task
- Dawson, Kelly, Spetch & Dupuis (2010) defined the reorientation task for a very simple kind of artificial neural network, the perceptron
- The perceptron was reinforced at the correct location, and not at the other locations
- The perceptron generated a wide variety of reorientation task phenomena



Nonmodular Reorientation

- The table below shows how the perceptron generates effects that might be interpreted as revealing a geometric module in a version of the reorientation task that provides both geometric and featural cues
- However, Dawson et al. (2010) point out that the perceptron necessarily uses nonmodular, associative treatments of all available cues

Table 4
Average responses of perceptrons to each arena location in Simulation 3. Location 4 was the reinforced location (i.e., the correct corner).

Response type	Arena location	Arena condition			
		Objects in original locations	Objects moved to location on right	Objects removed from rotational and correct locations	All objects removed
Perceptron activity	Near	0.04	0.45	0.04	0.06
	Rotational	0.09	0.29	0.40	0.40
	Far	0.03	0.01	0.03	0.06
	Correct	0.90	0.29	0.40	0.40
Choice rule	Near	0.04	0.43	0.05	0.07
	Rotational	0.08	0.28	0.46	0.43
	Far	0.03	0.01	0.03	0.07
	Correct	0.85	0.28	0.46	0.43

Cues To Reinforcement

- Perceptrons provide a nice associationist (and nonmodular) account of reorientation
- Visible cues provide information about possible reinforcement
- Cues can be local or geometric
- Perceptron response is literally a probability judgment about being reinforced, as shown by Dawson et al. (2009)

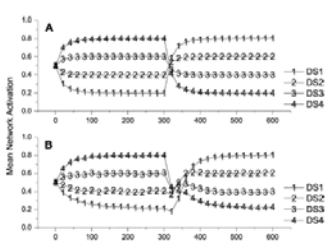


Fig. 1. Average responses of ten different perceptrons to each of the four stimuli as a function of training epoch. (a) Responses for networks from the first simulation which used standard training procedures. (b) Responses for networks from the second simulation which used an operant training procedure.

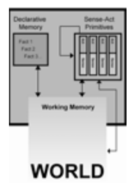
Embodying The Internal

- On the one hand, connectionism can be viewed as taking the body more seriously than can classical cognitive science because connectionism views the embodiment of the brain as critical to cognition
- On the other hand, connectionism is disembodied in the sense that it does not pay attention to the relation of the brain to the world at large
- “Highly artificial choices of input and output representations and poor choices of problem domains have, I believe, robbed the neural network revolution of some of its initial momentum. [...] The worry is, in essence, that a good deal of the research on artificial neural networks leaned too heavily on a rather classical conception of the nature of the problems” (Clark, 1997)

Andy Clark

The Extended Mind

- Embodied cognitive science views the mind as being scaffolded by, and leaking into, the world
- One cannot define the mind without defining the body and the world as interacting
- “By failing to understand the source of the computational power in our interactions with simple ‘unintelligent’ physical devices, we position ourselves well to squander opportunities with so-called intelligent computers” (Hutchins, 1995, p. 171)



Behavior-Based Robotics

- Behavior-based roboticists attempt to remove thinking or representation to speed processing up
- Why represent the world, when it can represent itself and be available to our active exploration?
- “In particular I have advocated situatedness, embodiment, and highly reactive architectures with no reasoning systems, no manipulable representations, no symbols, and totally decentralized computation” (Brooks, 1999, p. 170).
- “Consciousness is not something the brain achieves on its own. Consciousness requires the joint operation of brain, body, and world” (Noe, 2009, p. 10)

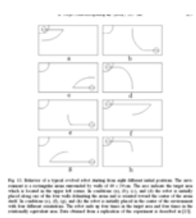
Rodney Brooks

Alva Noe

Evolving Reorientation

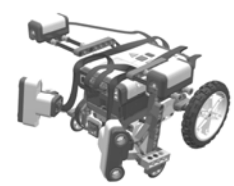
- Nolfi uses simple robots with an array of sensors capable of detecting walls, and controlling the speed of motors
- He has used evolutionary computation to develop a controller that delivers rotational error when a robot is placed in a reorientation arena
- “The sensory states of the robot permit it to indirectly measure the relative lengths of walls without directly comparing or representing length. It will use this sensed information to follow the long wall, which will necessarily lead the robot to either the goal corner or the corner that results in a rotational error, regardless of the actual dimensions of the rectangular arena” (Dawson, Dupuis & Wilson, 2010)

Stefano Nolfi



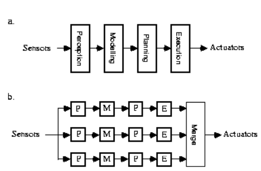
Case Study: antiSLAM

- Can we build a navigational robot that does not do SLAM, that does not build and use cognitive maps, but just reacts to its environment as it seems to navigate through it?
- Can we build it from LEGO, and abandon Nolfi’s evolutionary approach?
- Can it generate rotational error in the reorientation task, without using representations?

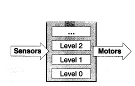


Layers Of Behaviors

- The ***subsumption architecture*** is an explicit reaction against the classical sandwich, and was pioneered by Rodney Brooks
- antiSLAM is programmed using a particular instance of the subsumption architecture



Classical Sandwiches



Subsumption Architecture

antiSlam Level 0

- “We start by building a complete robot control system which achieves level 0 competence. It is debugged thoroughly. We never alter that system” (Brooks, 1999, p.10)
- Our choice for Tortoise Level 0 is ***drive***

```
/*=====Level 0: Drive=================================
Feed the distance from each ultrasonic sensor to a motor.
The robot is wired contralaterally, and thus avoids all walls
equally. As a result, when it reaches a corner, it slows down
and ends up stopping in the corner "for free".
*/

task DriveRight(){
  while(true){
    OnFwd(RightMotor, RightSpeed);
  }
}

task DriveLeft(){
  while(true){
    OnFwd(LeftMotor, LeftSpeed);
  }
}
```

Level 1: Escape Corners

- **AntiSlam Level 1 is *escape***

```
/*=====Level 1: Escape========================================
If the motors move less than a stated threshold over a delay period,
the robot's sensors are temporarily overriden (zero sensitivity) as it
spins around. It ends up pointing approx. 45 degrees from the corner
when normal operation resumes.
*/

int Threshold, Delay;

task Retreat(){
  long RotCount;//Tracks motor rotation.
  while(true){
    RotCount = MotorRotationCount(LeftMotor) + MotorRotationCount(RightMotor);
    Wait(Delay);
    if((MotorRotationCount(LeftMotor)+MotorRotationCount(RightMotor)-RotCount)
        < Threshold){ //If, after Delay, the motors haven't moved enough:
      PlayTone(440, 500); //Beep to indicate feature flipping
      Sensitivity = 0; Reverse = 35; //Disable sensors, enable spin term
      Wait(4000);   //Time to spin in milliseconds
      Reverse = 0; Sensitivity = 1; //Return to default settings
      ResetRotationCount(LeftMotor); ResetRotationCount(RightMotor);
      Wait(500);
    }
  }
}
```

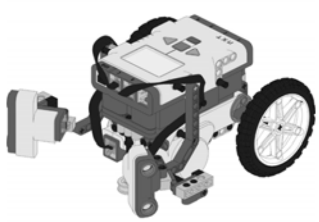
Level 2: Follow Walls

- **AntiSlam Level 2 is *Follow Walls***

```
  /*=====Level 2: Follow==========================================
  Introduce a bias in the robot's movement. This bias varies depending on its
  preferred side (which sensor it reads), and results in the robot turning toward
  a wall. The bias overcomes its natural wall aversion (level 0), causing it to
  follow a wall more closely on one side.
  */

  //Return the value of the sensor nearest the wall.
  int Nearest(bool hand){ //Note: "nearest" is defined by which handedness the robot's using.
True = left.

    if (hand) return SensorUS(LeftEar);
    else return SensorUS(RightEar);
  }

  bool preferred;

  task Seek(){
    int bias;
    while(true){
      bias = Nearest(preferred) * (-1) + 40; //Linear function: Wall dist. -> bias
      if (bias < 5) bias = 5; //Constraint: No zero or negative biases
      //Assign the bias to the correct motor and unbias the other one.
      if (preferred) {RightBias = bias; LeftBias = 0;}
      else {LeftBias = bias; RightBias = 0;}
    }
  }
```

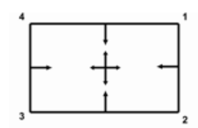
antiSLAM's Behavior

- **<u>This short video clip</u> on YouTube provides an example of this robot's behavior both in the "real world" and in the restricted world of the reorientation arena**

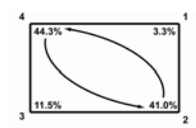


antiSLAM's Rotational Error

- **Using Levels 0 through 2 alone, antiSLAM will generate rotational error, without using cognitive maps, and without relying on associative cues**



Starting States for antiSLAM



Locations of turnarounds

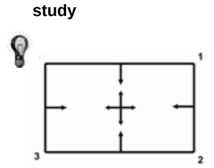
Level 3: Move To Light

- **AntiSlam Level 3 is *light attraction***
- **Light sensors affect motors to attract robot to light, while interacting with other levels**
- **Nolfi's robots were not sensitive to features**
- **Now a lit corner can be described as the "place with the correct landmark"**

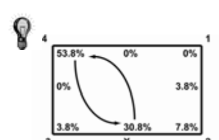
```
/*=====Level 3: Feature ==============================================
Enables and reads the light sensors (eyes) as a percentage based on "Vision"
(a sensitivity term), such that more light = more speed. Since the connection is contralateral, this results in the
     robot turning toward sources of light.
However, level -1 weighs this visual sense with the earlier ultrasonic sense,
allowing both terms to influence the robot's final behavior. */
int Vision; //The strength of the light sensors in percent.
task See(){
//Sets the strength of the robot's visual response to a scaled percentage.
  while(true){
    LVis = Sensor(LeftEye)*Vision/100;
    RVis = Sensor(RightEye)*Vision/100;
  }
}
```

Light Cooperates With Geometry

- **We can test antiSLAM when the light cue cooperates with geometric information**
- **Using all 3 levels, antiSLAM prefers the lit corner**
- **Note how its trajectory is altered compared to the previous study**



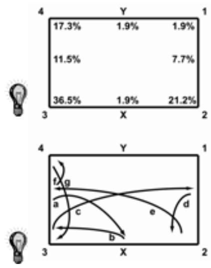
Starting States for antiSLAM



Locations of turnarounds

Light Competes With Geometry

- When cues are in conflict, antiSLAM generates animal-like behavior that reflects combined influences of local and geometric features
- It prefers the light, but also generates rotational error
- It also generates very complex trajectories – data not typically reported in animal studies
- Note that all of this was obtained “for free” by building a robot that would follow walls, escape corners, and be attracted to light
- <u>Might navigation be scaffolded exploration?</u>



The Bottom Line

- Navigation in general, and reorientation in particular, can be studied from a variety of perspectives
- A classical cognitive scientist examines rotational error as evidence for a geometric module
- A connectionist cognitive scientist examines reorientation as using a variety of learned cues as signals for reward
- An embodied cognitive scientist examines reorientation regularities as emerging from the world that an agent senses and acts upon
- Are all three positions completely different? Or is it possible that an integration amongst them is possible?