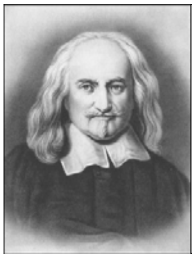
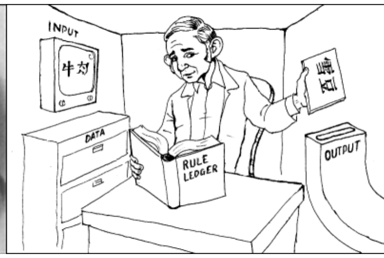
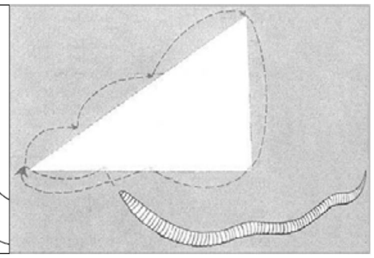
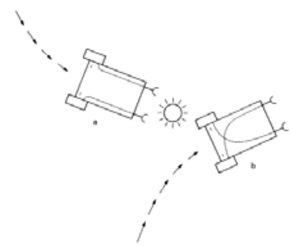




Animats, Minds, and Mobots (FYS 438)

Exploring Cognitive Science with Lego Robots

TR 8:00 – 9:20, Pettengill 127 & The Imaging Center (*the computer room*)

Professor William Seeley, 315 Hedge Hall
Office Hours, Fall 2014: TR: 12:30-1:30 & by appointment
wseeley@bates.edu

Course Description:
Philosophers have traditionally treated minds and bodies as somehow distinct, with the mind serving as the executive center, directing action by directing the activity of an otherwise passive body. *Embodied Cognition* is an alternative view within the field of cognitive science. The central claim of embodied cognition is that our bodies and minds have co-evolved as partners in cognition and behavior, and that the nature of intelligence and the structure of our minds are determined by the shapes of our bodies, by the ways different organisms have evolved to perceive and meaningfully engage with their environment. Minds and bodies are not distinct on this account, but rather our minds extend into our bodies. In this First Year Seminar we will use a series of autonomous robotics exercises developed for the Lego Mindstorms platform to explore this debate. The first half of the course covers conceptual issues. The second half of the course explores these conceptual issues through a series of robotics exercises. Along the way we will also introduce students to the role robotics research has played in the development of artificial intelligence and cognitive science.

Course Goals:
a) to introduce students to some of the central philosophical problems within cognitive science.
b) to introduce students to some fundamental concepts in program design and autonomous robotics.
c) to develop foundational research and writing skills necessary to engage with a liberal arts curriculum.

Texts:
- *Vehicles: Experiments in Synthetic Psychology*, Valentino Braitenberg (Cambridge, MA: MIT Press, 1986). ***(V)***
- ebooks in the Ladd Library holding. ***(ebook)***
- online resources ***(Onl)***
- electronic resources (pdfs and links) on Lyceum. **(*L)***.

Requirements: (descriptive, analysis, compare/contrast, synthesis/position

- ***Class participation***…poor class attendance will affect your final grade up to -10%.
- ***Descriptive Writing assignments*** (350-500 words each): annotated summaries of 4 readings. (10%)
- A **4 *page analysis papers*** due early in the semester (15% each).
- A ***6 page synthesis paper*** on an assigned topic due at the midterm (20%).
- A ***6 page synthesis paper*** on a topic of your choosing due before Thanksgiving (20%).
- R**evisions** of your ***6 page synthesis paper*** due by the final exam date (20%)
- ***Lab Notes & Project Presentations***: hands-on experience with autonomous agents (20%).
- There is ***no final exam*** in this class.

SCHEDULE OF READINGS:

Lecture 0. CONCEPTUAL ISSUES

This session introduces a) some central philosophical issues surrounding attempts to characterize intelligence and intelligent behavior, b) current discussions within *embodied cognition* about the role bodies might play in thinking and intelligence, and c) a methodological distinction between analytic and synthetic psychology.

Lecture 1. INTELLIGENCE & INTELLIGENT BEHAVIOR I

This session opens discussion about a) the relationship between intelligence and behavior and b) the role perspective, or frames of reference, plays in characterizing a behavior as intelligent.

- Daniel Dennett, "True Believers: The Intentional Strategy and Why It Works," in ed. John Haugeland *Mind Design II* (Cambridge, MA: MIT Press, 1997), 57-80. ***(L)***
- Valentino Braitenberg, *Vehicles: Experiments in Synthetic Psychology* (Cambridge, MA: MIT Press, 1984), 1-14. ***(V)***
- LEGO PROJECT: Are Vehicles 2a/b or 3a/b intelligent?

Lecture 2. INTELLIGENCE & INTELLIGENT BEHAVIOR II

This session extends the discussion of intelligent behavior to several case studies: Darwin's discussion of the behaviors of earthworms, Kholer's discussion of the problem solving behaviors of chimpanzees, and some more recent work on the reasoning capacities of capuchins, chimpanzees, and cotton-topped tamarins.

- Charles Darwin, *The Formation of Vegetable Mould Through the Actions of Worms, with Observations on Their Habits*, New York: D. Appleton and Company, 1896, 55-89. ***(ebook, Ladd Library)*** http://www.biodiversitylibrary.org/title/48549#page/71/mode/1up
- Wolfgang Kholer, *The Mentality of Apes*, *2nd Edition*, New York: Harcourt, Brace, & Company, 1927, 7-9; 39-45; 135-139. ***(L)***
- Clive D. L. Wynn, *Do Animals Think? (*Princeton, N.J.: Princeton University Press, 2004), 60-64. ***(L)***

Lecture 3. INTELLIGENCE & INTELLIGENT BEHAVIOR III

- This session continues the discussion of the relationship between intelligence and intelligent behavior. The goal of the session is to open the discussion and explore our own common sense intuitions about the case studies and thought experiments introduced in in Sessions 1 and 2.

Lecture 4. THE COMPUTATIONAL THEORY OF MIND: THE SYMBOL SYSTEM APPROACH

This session introduces *the computational theory of mind* that has dominated modern philosophical thinking about intelligence and the classical *symbol system model* that serves as the foundation for much recent research in artificial intelligence and cognitive science.

- Thomas Hobbes, *The Metaphysical System of Hobbes in Twelve Chapters from Elements of Philosophy Concerning Body together with Briefer Extracts from Human Nature and Leviathan* (Chicago: Open Court, 1658/1913), chapter 1, pages 6-9. ***(ebook)*** *https://archive.org/stream/cu31924014604007#page/n37/mode/2up*
- Thomas Hobbes, *Leviathan* (New York: Penguin, 1651/1968), chapter 5, pages 47-49. ***(ebook)*** https://archive.org/stream/ost-history-leviathan/Leviathan#page/n45/mode/2up
- John Haugeland, “What Is Mind Design?” in ed. John Haugeland, *Mind Design II* (Cambridge, MA: MIT Press, 1997), 1-28. ***(L)***
- Stephen E. Palmer, "Constructivism," *Vision Science* (Cambridge, MA: MIT Press, 1999), 55-59. ***(L)***

Lecture 5. THE COMPUTATIONAL THEORY OF MIND: THE CHINESE ROOM PROBLEM

This session introduces a standard objection to symbol system models in artificial intelligence. The argument suggests that the symbols and operations "in the head" of a symbol system are not meaningfully connected to the world they are taken to represent. If correct this would entail that the "thoughts" of these kinds of intelligent systems are not about the world they describe, and so can not constitute an understanding of either their world or their behaviors within it.

- John Searle, "Minds, Brains, & Programs," in ed. John Haugeland, *Mind Design II* (Cambridge, MA: MIT Press, 1997), 183-204. ***(L)***
- Rolf Pfeifer and Christian Scheir, "The Symbol Grounding Problem," *Understanding Intelligence*, Cambridge, MA: MIT Press, 1999, 69-71. ***(L)***
- Searle and the Chinese Room Argument, Parts 1 & 2, *The Mind Project: Consortium on Cognitive Science Instruction*. ***(Onl)***
  http://www.mind.ilstu.edu/curriculum/searle_chinese_room/searle_chinese_room.php

Lecture 6. KNOWLEDGE REPRESENTATION, COMMON SENSE, AND THE FRAME PROBLEM

This session introduces the frame problem as a second objection to symbol system models in artificial intelligence. The frame problem suggests that knowledge representation in symbol systems is too inflexible to model the smooth adaptability of everyday interactions with a dynamic environment. This has really been the sticking point for symbol system approaches and the point of departure for alternative approaches to artificial intelligence in autonomous robotics.

- Rolf Pfeifer and Christian Scheir, "The Problems of Embodiment and Situatedness," *Understanding Intelligence* (Cambridge, MA: MIT Press, 1999), 63-69; 71-73). ***(L)***
- Margaret Boden, *Mind as Machine*, Volume 2 (New York: Oxford University Press, 2006), 772-774. ***(L)***
- Jack Copeland, "Knowledge Representation" and "Micro-Worlds," *Artificial Intelligence: A Philosophical Introduction* (Malden, MA: Blackwell Publishers, 1993), 91-95. ***(L)***

Lecture 7. BEHAVIOR BASED ROBOTICS

This session introduces Rodney Brooks' *subsumption architecture* and the behavior-based robotics approach in artificial intelligence that it spearheaded. Brooks by-passed the frame problem. His robots are designed to react directly to signal properties in the environment that are of value to their behavior. Brooks used this *insect intelligence strategy* to model complete elemental behaviors modularly, for instance simple locomotion and object avoidance, and then connected these modular behaviors in hierarchical structures to constructed robots that could operate autonomously in simple environments.

- Rodney Brooks, "Intelligence without Representation," in ed. John Haugeland, *Mind Design II* (Cambridge, MA: MIT Press, 1997), 395-420. ***(L)***
- Maja J. Mataric, "Don't Think, REACT!" in *The Robotics Primer* (Cambridge, MA: MIT Press, 2007), 161-176. ***(L)***
- LEGO PROJECT: *Vehicles* and subsumption architectures

Lecture 8. ENVIRONMENTS, NICHES, & AFFORDANCES

This session introduces some fundamental principles of the embodied approach to modeling behavior. The goal of the session is to introduce the fundamental concept of an *affordance*, explore how organisms exploit signal properties in the environment in the production of intelligent behaviors, and discuss how these processes define the *environment* and *ecological niche* of an organism.

- Stephen E. Palmer, "Ecological Optics" and "Direct Perception," *Vision Science* (Cambridge, MA: MIT Press, 1999), 53-55. ***(L)***
- Richard C. Lewontin, "Science as Social Action," *Biology as Ideology* (New York: Harper Perennial, 1992), 107-128. ***(L)***
- Anthony Chemero, "An Outline of a Theory of Affordances," *Ecological Psychology,*15(2), 2003: 181-195. ***(L)***

Lecture 9. ECOLOGICAL BALANCE AND MORPHOLOGICAL COMPUTATION

The goal of this session is to continue the discussion of the embodied approach to modeling intelligent behavior by introducing the concepts of *ecological balance* and *morphological computation*, or the idea that our bodies have developed in part as adaptations that help filter and structure, or *scaffold*, information for cognition. Theorists at one extreme have taken this idea to suggest that our minds extend into our bodies.

- Rolf Pfeifer and Josh Bongard, *How the Body Shapes the Mind* (Cambridge, MA: MIT Press, 2007), 123-137 ***(L)***
- LEGO PROJECT: ecological balance and morphological computation

Lecture 10. BRAITENBERG VEHICLES

The goal of this session is to use our LEGO Braitenberg Vehicles to explore the concepts introduced in the discussion of embodied, behavior-based approaches to artificial intelligence and cognitive modeling.

- LEGO PROJECT: Braitenberg, *Vehicles* 1-6: 1-28. ***(V)***

Lecture 11. BRAITENBERG VEHICLES

The goal of this session is to use our LEGO Braitenberg Vehicles to explore the concepts introduced in the discussion of embodied, behavior-based approaches to artificial intelligence and cognitive modeling.

- LEGO PROJECT: Braitenberg, *Vehicles* 1-6: 1-28. ***(V)***

Lecture 12. DISCUSSION: BEHAVIOR-BASED ROBOTICS AND COGNITIVE SCIENCE

The goal of this session is to explore different ways behavior based robotics have contributed to cognitive science .

- Pierre Yves Oudeyer, "On the impact of robotics in behavioral and cognitive sciences: from insect navigation to human cognitive development," *IEEE Transactions on Autonomous Mental Development*, 2(1), 2010: 2-16. ***(Onl)***

  http://www.pyoudeyer.com/IEEETAMDOudeyer09.pdf
- Andy Clark, "Dynamics," *Mindware*, 2nd Edition (Cambridge, MA: MIT Press, 2014), 140-141; 145-156. ***(L)***
- LEGO PROJECT: Braitenberg, *Vehicles* 1-6: 1-28. ***(V)***

FALL BREAK: October 15 – October 19!!!!

Lecture 13. DIDABOTS – Tidy Robots

The goal of this session is to use the *Braitenberg Vehicles* platform we have developed with our LEGO robots to explore *stimergy* as a mechanism for coordinating cooperative group behaviors that can be interpreted as intelligent at a group level, but not the individual level. This session extends our discussion of the different ways morphology and the structure of the local environment can be used to scaffold information processing.

- Verena Hafner. “An Example for (Reactive) Cooperative Behavior: The Swiss Robots." Retrieved August 31, 2014: http://www.verena-hafner.de/teaching/didabots.pdf ***(Onl)***

  http://www.verena-hafner.de/teaching/didabots.pdf
- Marinus Maris and René te Boekhorst, "Exploiting Physical Constraints: Heap Formation through Behavioral Error in a Group of Robots," in ed. M. Asada, *Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1996, 1655-1660. ***(L)***
- LEGO PROJECT: Didabots.

Lecture 14. DIDABOTS – Tidy Robots

This session continues our exploration and discussion of Didabot behavior.

- Owen Holland and Chris Melhuish, "Stimergy, Self-Organization, and Sorting in Collective Robotics," *Artificial Life*, 5(2), 1999: 173-202. ***(Onl)***

  http://www.csupomona.edu/~ftang/courses/CS599-DI/notes/papers/stigmergy%202.pdf
- LEGO PROJECT: Didabots.

Lecture 15. LEMMINGS - Arturito

The goal of the following three sessions is to further explore agent-environment interactions and the role of stimergy as a mechanism for coordinating cooperative behaviors.

- Arturo Perez and Michael R. W. Dawson, "A Brick Sorting Lego Robot," *Eureka*, 4(1), 2014: 19-23, ***(Onl)***

  http://www.bcp.psych.ualberta.ca/research/pdfstuff/Perez1.pdf
- LEGO PROJECT: Lemmings.

Lecture 16. LEMMINGS - Arturito

The goal of this session is to continue our exploration and discussion Didabots and Lemmings

- Michael R. W. Dawson, Brian Dupuis, and Michael Wilson, " Lemmings," *From Bricks to Brains* (Edmonton, Alberta: Athabasca University Press, 2010), 253-262. ***(Onl)***

  http://www.aupress.ca/books/120175/ebook/08_Dawson_et_al_2010-From_Bricks_To_Brains.pdf
- LEGO PROJECT: Lemmings

Lecture 17. LEMMINGS - Arturito

The goal of this session is to continue our exploration and discussion Didabots and Lemmings.

- Maja J. Mataric, "Go Team!" in *The Robotics Primer* (Cambridge, MA: MIT Press, 2007), 233-254. ***(L)***
- LEGO PROJECT: Lemmings

Lecture 18. **NAVIGATION: CONCEPTUAL ISSUES**

The goal of this session is to introduce navigation as a computational problem and the SLAM (simultaneous localization and mapping) model for robot navigation. The standard computational approach suggests that navigation requires mapping the local environment, identifying the agent's orientation to local landmarks, and choosing a heading – a canonical example of the perceive-plan-act model for intelligent behavior that embodied approaches challenge. In the following three sessions we will explore AntiSLAM as a non-representational, embodied solution to this problem.

- Edwin Hutchins, "Navigation as Computation," *Cognition in the Wild (Cambridge, MA: MIT Press, 1995), 49-116.* ***(L)***
- Maja J. Mataric, "Go Places, Navigation," in *The Robotics Primer* (Cambridge, MA: MIT Press, 2007), 223-232. ***(L)***

Lecture 19. **NAVIGATION: AntiSLAM**

The goal of the following three sessions is to replicate and evaluate Dawson et al's Anti-SLAM model for robot navigation. Central to Dawson's case is the claim that his robots replicate animal behaviors in *the reorientation task*. In this session we introduce the reorientation task and the AntiSLAM robot.

- Ken Cheng, "Whither Geometry? Troubles of the Geometric Module," *TRENDS in Cognitive Sciences*, 12(9), 2008: 355-361. ***(Onl)***
  http://www.sciencedirect.com/science/article/pii/S1364661308001782#
- Michael R. W. Dawson, Brian Dupuis, and Michael Wilson, " AntiSLAM (conceptual issues)," *From Bricks to Brains* (Edmonton, Alberta: Athabasca University Press, 2010), 268-278. ***(Onl)***
  http://www.aupress.ca/books/120175/ebook/09_Dawson_et_al_2010-From_Bricks_To_Brains.pdf
- Michael R. W. Dawson, Brian Dupuis, and Michael Wilson, " AntiSLAM (building & programming)," *From Bricks to Brains* (Edmonton, Alberta: Athabasca University Press, 2010), 282-297.***(Onl)***
  http://www.aupress.ca/books/120175/ebook/09_Dawson_et_al_2010-From_Bricks_To_Brains.pdf
- LEGO PROJECT: Anti-SLAM

Lecture 20. **NAVIGATION: AntiSLAM**

The goal of this session is to replicate and evaluate Dawson study of *the reorientation task*.

- Michael R. W. Dawson, Brian Dupuis, and Michael Wilson, " AntiSLAM (results)," *From Bricks to Brains* (Edmonton, Alberta: Athabasca University Press, 2010), 297-308.***(Onl)***
  http://www.aupress.ca/books/120175/ebook/09_Dawson_et_al_2010-From_Bricks_To_Brains.pdf
- LEGO PROJECT: Anti-SLAM

Lecture 21. **NAVIGATION: AntiSLAM**

The goal of this session is to replicate and evaluate Dawson study of *the reorientation task*.

- Michael R. W. Dawson, Debbie M. Kelly, Marcia L. Spetch, and Brian Dupuis, "Using Perceptrons to Explore the Reorientation task," *Cognition*, 114(2), 2010: 207-226. ***(Onl)***
  http://www.sciencedirect.com/science/article/pii/S0010027709002194#
- LEGO PROJECT: Anti-SLAM

Lecture 22. NAVIGATION: TOTO'S RAT BRAIN

The goal of this class is to explore Maja Mataric's use of landmarks to represent space in a navigation task for her robot Toto. Mataric's behavior-based robotics model is more flexible that Dawson's. Our challenge will be to implement a version of her model in our LEGO robots.

- Maja J. Mataric, "Navigating with a Rat Brain: A Neurobiologically-Inspired Model for Robot Spatial Representation," in eds. J. A. Meyer and S. Wilson, *From Animals to Animats: International Conference on Simulation of Adaptive Behavior* (Cambridge, MA: MIT Press, 1990), 169-175. ***(L)***
- Maja J. Mataric, "Think the Way You Act, Behavior-Based Control" in *The Robotics Primer* (Cambridge, MA: MIT Press, 2007), 187-205. ***(L)***
- LEGO PROJECT: Toto

Lecture 23. NAVIGATION: TOTO'S RAT BRAIN

The goal of this class is to continue to explore the behavior of Maja Mataric's robot, Toto.

- LEGO PROJECT: Toto

Lecture 24. NAVIGATION: TOTO'S RAT BRAIN

The goal of this class is to continue to explore the behavior of Maja Mataric's robot, Toto.

- LEGO PROJECT: Toto

ASSIGNMENTS: All assignments must be handed in both in hard copy and electronically via the dropbox for that assignment on LYCEUM

<u>Descriptive Writing</u>: The goal of this assignment is to produce a 350-500 word annotated summary of the argument in a reading. Your task is to describe the issue in question, the argument provided by the authors for their position, and the key points of evidence used in their argument. You should close with a brief evaluation of whether the argument/evidence is successful in establishing the author's position. These descriptions should model the reading notes you would take to prepare a text for class discussion or the entry you would prepare for the reading for an annotated bibliography.

<u>Due Date</u>: Friday at the end of Weeks 2, 5, and 10

<u>Analysis Paper (1000 words)</u>: The goal of this paper is to critically evaluate the argument presented in syllabus reading identified by the prompt (it may take some sleuthing to identify the reading). This paper should be treated as an extended version of your descriptive writing assignments. However, extra focus should be placed on critically evaluating the reasoning and evidence presented in support of the argument in the reading. Please choose one of the following prompts for your paper.

A1) Does *the robot reply* answer Searle's *chinese room argument*?

A2) Has Brooks resolved *the frame problem*?

<u>Due Date</u>: Friday at the end of Week 4
<u>Re-write</u>: Wednesday of week 6!

Synthesis I (1800 words): The purpose of this paper is to demonstrate that you can identify & evaluate a standard argument in the literature and synthesize the diverse range of material covered in the first half of the semester into a coherent position. Please answer one of the following prompts.

S1a) Are the capuchins and tamarins Wynne describes as (or more) intelligent than Darwin's earthworms? Why or why not?
S1b) Is behavior-based robotics an adequate method for modeling intelligent behavior? Please make reference to the arguments in both Brooks and Oudeyer's papers in your evaluation.
S1c) Are *Vehicles*, *Didabots*, or *Lemmings* intelligent? Could they be?
S1d) Are *Vehicles* or *Didabots* more or less intelligent than earthworms?

<u>Due date</u>: Friday at the end of Week 9

Synthesis II (1800 words): The purpose of this paper is to demonstrate that you can identify & evaluate a standard argument in the literature, synthesize the diverse range of material covered on the syllabus into a coherent position, and incorporate comments on revisions to a draft. Please write on a topic of your choosing.

Topic Due Date:	Week 8
First Draft Due Date:	Friday at the end of Week 11 (Friday before Thanksgiving)
Comments Back:	Monday after Thanksgiving
Revisions Due Date:	The day of the robot rodeo during exam week.

<u>Lab Notes & Robot Rodeo</u>: We will divide ourselves into teams of two students each and work through a range of robotics exercises in class using the Lego Mindstorms robots system and the programming language Robot C. These exercises are designed to help us explore the power (and shortcomings) of behavior based animat approaches to AI. Teams are required to keep a journal or ***lab notes*** documenting their work. Documentation should include videos of robot behavior, copies of your successful programs in Robot C, any written notes or intermediate programming solutions, as well as a narrative describing the process that led to team solutions to the robot exercises. The lab notes are a critical record of your robotics work outside of class. We will meet during the exam period in *The Imaging Center* for a ***Robot Rodeo*** where teams will demonstrate their successful robots.

<u>Due date</u>: The final exam date.

Some Miscellaneous Notes and Guidelines:

Moral behavior is the grounds for, and the framework of, a healthy society. In this regard it is each of our responsibility as an individual within the community of our classroom to act responsibly. This includes following the rules and guidelines set out by Bates College for academic behavior. Plagiarism is a serious matter. It goes without saying that each of you is expected to do his or her own work and to cite EVERY text that is used to prepare a paper for this class.

Please familiarize yourself with the guidelines for academic integrity posted on the Bates Website:
http://www.bates.edu/entering/policy/judicial-affairs/code-of-student-conduct/academic-misconduct/

This is a seminar. This means that the content of the course, and our progress through the syllabus, should ideally be student driven. I have designed the course to allow us some flexibility so that we can spend more time on issues of interest to the class. I reserve the right to make changes to the syllabus as we go along in order to accommodate our interests as they emerge in class discussions. I will also occasionally upload supplementary materials to *Lyceum* for students interested in pursuing particular issues beyond class discussion.

SCHEDULE OF READINGS

The reading schedule that follows is a loose guideline for our progress through the syllabus. It is open to change at the Professor's discretion contingent on the pace of the class and evolving interests of the group.

Date	Readings	Assignments (due Fridays: 5pm)
0: 09/01	General Discussion: Thinking? Intelligence? Embodied Cognition? Synthetic Psychology?	
1: 09/03	Dennett, True Believers: 57-79. ***(L)*** Braitenberg, Vehicles 1-3: 1-14. ***(V)*** LEGO PROJECT: Are Vehicles 2a/b intelligent?	
2: 09/09	Darwin: *The Formation of Vegetable Mould Through the Actions of Worms, with Observations on Their Habits*,The Habits of Worms II (excerpt): 55-98. ***(ebook, Ladd Library)*** Kohler: *The Mentality of Apes*: 7-9; 39-45; 135-139. ***(L)*** Wynne: *Do Animals Think?*, Modern Logic for Primates: 60-64. ***(L)***	
3: 09/11	Discussion of earthworms, monkeys, & apes *(continued)*	**Descriptive Writing I**
4: 09/16	Hobbes, The Elements of Philosophy, Ch.1: pp. 6-9. ***(ebook)*** Hobbes, *Leviathan*, Ch. 5: 47-49. ***(ebook)*** Haugeland, What is Mind Design?: 8-21. ***(L)*** Palmer, *Vision Science*, Constructivism: 55-59.	
5: 09/18	Searle, Minds, Brains, and Programs: 183-204. ***(L)*** Pfeifer & Scheir, *Understanding Intelligence*: 69-71. **(L)** The Mind Project: The Chinese Room Argument, Parts 1 & 2. ***(Onl)***	
6: 09/23	Pfeifer & Schier, *Understanding Intelligence*: 64-69; 71-73. ***(L)*** Boden, *Mind as Machine V.2*: 772-774. Copeland, *Artificial Intelligence*: 91-92.	
7: 09/25	Brooks, Intelligence without Representation: 395-420. ***(L)*** Mataric, Don't think, REACT!: 161-176. ***(L)*** LEGO PROJECT: *Vehicles* & subsumption architectures	**Analysis Paper**

8: 09/30	Palmer, *Vision Science*, Ecological Optics: 53-55. ***(L)*** Lewontin, Science as Social Action: 107-128. ***(L)*** Chemero, An Outline of a Theory of Affordances: 181-195. ***(L)***	
9: 10/02	Pfeifer & Bongard, *How the Body Shapes…*: 123-137. ***(L)*** LEGO PROJECT: ecological balance & morphological computation	**Descriptive Writing II**
10: 10/07	Braitenberg, *Vehicles*, Vehicles 1-6: 1-28. ***(B)*** LEGO PROJECT: *Vehicles* 1-6	
11: 10/09	Braitenberg, *Vehicles*, Vehicles 1-6: 1-28. ***(B)*** LEGO PROJECT: *Vehicles* & subsumption architectures	**Analysis I rewrite (10/29 @ 5pm)**
12: 10/14	Oudeyer, On the Impact of Robotics…:2-16. ***(Onl)*** Clark, *Mindware*, Dynamics: 140-1; 145-156. ***(L)***	
Fall Recess: 10/15 – 10/19		
13: 10/21	LEGO PROJECT: Didabots - Tidy Robots Hafner, An example of cooperative behavior: 1-3. ***(Onl)*** Maris & te Boekhorst, Exploiting Physical Constraints: 1-6. ***(L)***	
14: 10/23	LEGO PROJECT: Didabots - Tidy Robots Holland and Melhuish, Stimergy, Self-Organization, and…: 1-30. ***(Onl)***	
15: 10/28	LEGO PROJECT: Lemmings Perez and Dawson, A Brick Sorting LEGO Robot: 19-23. ***(Onl)***	
16: 10/30	LEGO PROJECT: Lemmings Dawson et al, *From Bricks to Brains,* Embodiment, Stimergy, and Swarm Intelligence: 253-262. ***(Onl)***	
17: 11/04	LEGO PROJECT: Lemmings Mataric, *The Robotics Primer*, Go Team!: 233-254. ***(L)***	
18: 11/06	LEGO PROJECT: Navigation Hutchins, *Cognition in the Wild*, Navigation: 49-116. ***(L)*** Mataric, *The Robotics Primer*, Going Places: 223-232. ***(L)***	**Synthesis I (11/07 @ 5pm)**
19: 11/11	LEGO PROJECT: Navigation (AntiSLAM) Dawson et al, *From Bricks to Brains,* Totems, Toys – or Tools?: 263-283. ***(L)***	
20: 11/13	LEGO PROJECT: Navigation (AntiSLAM) Dawson et al, *From Bricks to Brains,* Totems, Toys – or Tools?: 296-308. ***(L)***	**Descriptive Writing III**

21: 11/18	LEGO PROJECT: Navigation (AntiSLAM) Dawson et al, Using Perceptrons…: 207-226. ***(Onl)***	
22: 11/20	LEGO PROJECT: Navigation (Toto) Mataric, Navigating with a Rat Brain…: 169-175. ***(L)*** Mataric, *The Robotics Primer*, Think the Way You Act, Behavior Based Control: 187-205. ***(L)***	**Synthesis II (11/21 @ 5pm)**
23: 12/02	LEGO PROJECT: Navigation (Toto)	
24: 12/04	LEGO PROJECT: Navigation (Toto)	
Final 12/12	12/12, 1:15-3:15 Robot Rodeo	**- Presentation of Team Work.** **- Lab Notes.** **- Revised Draft of Synthesis II.**

FYS 438, Animats, Minds, and Mobots: Exploring Cognitive Science with Lego Robots
Professor William Seeley
Robotics Exercises
Fall 2015

Course Summary:
Philosophers have traditionally treated minds and bodies as somehow distinct, with the mind serving as the executive center, directing action by directing the activity of an otherwise passive body. *Embodied Cognition* is an alternative view within the field of cognitive science. The central claim of embodied cognition is that our bodies and minds have co-evolved as partners in cognition and behavior. The nature of intelligence and the structure of our minds is determined by the shapes of our bodies, by the ways different organisms have evolved to perceive and meaningfully engage with their environment. Minds and bodies are not distinct on this account, but rather our minds extend into our bodies. In this First Year Seminar we will use a series of autonomous robotics exercises developed for the Lego Mindstorms platform to explore this debate. Along the way we will also introduce students to the role robotics research has played in the development of artificial intelligence and cognitive science.

Course Goals:
a) to introduce students to some of the central philosophical problems within cognitive science.
b) to introduce students to some fundamental concepts in program design and autonomous robotics.
c) to develop foundational research and writing skills necessary to engage with a liberal arts curriculum.

Sample Robotics Exercises for FYS 483: One significant challenge in artificial intelligence is to build systems/machines that can flexibly adapt to conditions not explicitly specified in what they have been programmed to do. This is an essential capacity for intelligent behavior in a dynamic and unpredictable environment. In these exercises we explore some simple concrete solutions to this challenge.

Wander: The first step in autonomous robotics is to build a machine that can explore its environment without getting stuck. Our first robot will use sonar to avoid objects so that it can run in any environment until it runs out of batteries.

Light Seekers/Avoiders: Once a platform for exploring has been built we need to add some sensitivity to the environment. Our next project will be to build a series of machines that interact with pools of light projected onto the floor. The goal of this project is to explore the concept of embodiment by experimenting with the way different connections between sensors and motors and different physical configurations of sensors affect the robot's behaviors.

Cooperators: Many insect and animal communities solve problems through apparently cooperative behavior. This collective behavior is often not “directed,” but rather emerges from simpler individual behaviors. We will build a two different kinds of robots that work alone or in groups to tidy up a messy room cluttered with paper boxes or Lego bricks by simply avoiding piles of boxes/bricks and each other.

Navigation: Most of the robots we will build produce behaviors that appear intentional but are really governed by simple reflexes. Of course what we are most interested in is more directed forms of intelligent behavior. In our final exercise we will explore whether the reactive procedures used in the previous robots can be used to teach a robot to orient to landmarks and use them to efficiently navigate through an environment (rather than accidentally fall upon a path).

Exercise Sets:

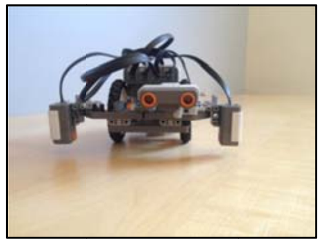
Please complete the following exercise sets. Make sure to load all of your intermediate work including programs, video documentation of your robot's behavior, and design/programming/test-run notes to your *Robot Group Folder* on the *etna server*. You will need to upload a) final programs, b) video documentation, and c) a narrative description of your design/programming/test-run work to ***BOTH*** the your ***groups folder*** and the ***dropbox on LYCEUM*** for each project.

The goal of your design/programming/test-run notes should be to provide a running narrative of the work you have done to date. Make sure to highlight the challenges you faced, the strategies you developed to overcome any related problems (including modifications to the robot itself), and how you settled on your final solutions.

* REMEMBER: *SLOW WINS THE RACE*. These are robots, not humans, their attention span is less distractible. Experimenting with slower motor speeds often enhances their success.

Exercise Set #1	**Braitenberg Vehicles**
Exercise Set #2	**Didabots**
Exercise Set #3	**Lemmings / Arturito**
Exercise Set #4	**antiSLAM**
Exercise Set #5*	**Toto (optional advanced project)**

Exercise Set #1. Braitenberg Vehicles (see Braitenberg, *Vehicles* for a description of the target behaviors for these robots).



Assignment: NXT-G: BV2a (afraid), BV2b **(**aggressive), BV3a (curious), BV3b (cautious)

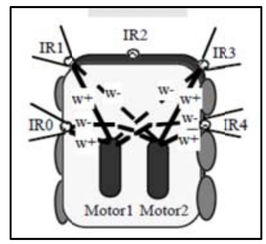
Robot C: BV2a, BV2b, BV3a, BV3b
BV3a2a (curious about light but runs away if it gets too bright)

Challenge: As we initially programmed the BV3a2a it gets stuck in the light because it kicks back into the 3a routine as soon as one of its two light sensors leaves the pool of light created by the floodlight. Why does this occur? Can you solve this problem?

Sample Program see "BS-BV2a-GeneralProgrammingInstructions.c" in the *Bill-Juergen-RBS* groups folder for general programming instructions.

```
#pragma config(Sensor, S1,              Light1,                                  sensorLightInactive)
#pragma config(Sensor, S2,              SONAR2,                                  sensorSONAR)
#pragma config(Sensor, S4,              Light4,                                  sensorLightInactive)
#pragma config(Motor,    motorA,                        motorA,                   tmotorNormal, PIDControl, encoder)
#pragma config(Motor,    motorC,                        motorC,                   tmotorNormal, PIDControl, encoder)
//*!!Code automatically generated by 'ROBOTC' configuration wizard                               !!*//

task main() {

        while(true) {

                if (SensorValue(SONAR2) > 20) {         //* Braitenberg 3a
      motor[motorA] = -(60 - SensorValue(Light1));
      motor[motorC] = -(60 - SensorValue(Light4));
        }

                else {                                  //* standard avoid
                        motor[motorA] = 0;
                        motor[motorC] = 0;
                        wait1Msec(250);
                        motor[motorA] = 35;
                        motor[motorC] = 75;
                        wait1Msec(500);
                }

        }
}
```

Exercise Set #2 . Didabots: The goal of the Didabots exercises is to replicate Maris and te Boekhorst's heap formation experiments with the original Didabots (derived from didactic robots). The Didabots provide illustrations of self-structuring behaviors, *stigmergy* (Grassé, 1959), and cooperative *swarm intelligence* as are exhibited in ant navigation and termite mound building behaviors. In all of these cases the movements or behaviors of an organism (themselves reflexively cued by the environment) restructure its environment which in turn reflexively cue further behaviors. The argument is that evolution exploits this type of environment-organism coupling to produce complex behaviors in social insects like ants and termites. *A potentially interesting final paper would be to discuss the degree to which stigmergic behaviors generalize to human intelligence.*



SET-UP: push the chairs under the counter; use the 2 large corral parts to make a 2 panel x 1 panel rectangle as long as the space between the chairs and the cabinet; overlap the single panel ends in front of the chairs- leave the cabinet end open end to cabinet – notice the 2-panels overlap the sides of the cabinet; at the open (cabinet) set the small corral panels to make a 2 panel wall; use the small paper boxes (white, orange, yellow); arrange the paper boxes in a 6 (short way) x 9 pattern as in the photo above; start oriented 45 degrees away from the Imaging Lab corner of the corral (side of cabinet farthest from the window).

Assignment:	NXT-G:	none	
	Robot C:	Didabot-simple	with a GO(straight) drive behavior
		Didabot –dynamic	with motor speeds coupled to SONAR values in GO using a BV architecture
		Didabot-BVL	with motor speeds coupled to light sensors in GO; experiment with different BV's, i.e. 2a/b 3a/b.

Exercise Set #2. Didabots (*continued*)

Data Collection: Part of the goal of this project is to replicate Maris and te Boekhorst's results. They give figures for: a) how quickly on average 1, 2, & 3 Didabots are able to organize the paper blocks in their environment into heaps; how many heaps are formed on average in each condition (1,2, or 3 robots); how many blocks on average are in each heap in each condition; and how many blocks are lost along the wall.

Please find the *Didabot Excel Spreadsheet* in the Groups Folder and fill in this data for your robots behaviors. This will require you to partner up with other groups. For now let's not worry about making sure we manage to get results from all the different combinations of different groups.

* Don't forget to record your data separately in your files as well.

** Don't forget that if you overwrite someone else's data in the *Didabot Excel Spreadsheet* it will be lost from that location and have to be re-entered…be careful please!

*** When we rebuild the robots for the antiSLAM project we will return to this project, settle on a common shared program, and collect this data.

Challenge #1: How does the choice of using a GO(straight), SONAR-BV, or LIGHT-BV drive behavior behavior influence the behavior of the robots? Are the BV's more or less efficient? If they don't make heaps…they are way less efficient!

Challenge #2: The original Didabots used 4 infrared sensors at 45 and 180 degrees that gave them some sensitivity to looming walls as they approached them. We are using 2 ultrasound sensors at 45 degrees with a wider blind spot. How does that affect the behaviors of our Didabots? Do they get stuck on walls? If so can you solve this problem?

Sample Program: Browse the groups folders to see how your colleagues in class have tackled these challenges and bootstrap your own solution. The general subsumption architecture for a Didabot(simple) looks like this:

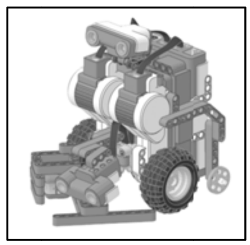
Level 2. AVOID WALLS
if (S1 < n1) && (S2 < n1) then AVOID
Level 1. DROP BLOCKS
If S1 < n2 then TURN AWAY
If S2 < n2 then TURN AWAY
Level 0. GO(biased)
motor speeds should be offset by 1%.

Exercise Set #3

Lemmings / Arturito: The Lemmings project is designed to further explore the kinds of stigmergetic & collective behaviors that lie at the foundation of autonomous robotics and dynamic systems approaches to modeling intelligence. The lemming is designed to model *ant brood sorting behaviors*. The behavior of the Lemmings are more complex than the Didabots because they can sort elements of their environment relative to their appearances, here, putatively, by the color of the bricks.

In an ant nest larvae are sorted annularly with larger larvae sorted in concentric bands by increasing size around a center. The Lemmings clear white bricks to the wall, leaving black bricks in the center of the room.

The Lemmings orient to targets with a single ultrasonic sensor. Arturito orients to targets using two light (intensity) sensors and a Braitenberg architecture. Both robots identify targets using a light (intensity) sensor and AVOID walls using a separate ultrasonic sensor.



Assignment:	NXT-G:	none	
	Robot C:	Lemming	SONAR orienting procedure
		Arturito	BV(Light) orienting behavior

Data Collection:

Part of the goal of this project is to replicate Perez and Dawson's results. They give figures for how quickly on average 1, 2, & 3 Lemmings/Arturitos are able to sort the Lego blocks in their environment.

I have added a pair of yellow and a pair of blue bricks to the target set. I am interested in whether the robots will sort these as white(yellow) and black(blue) bricks. I am also interested in the number of black/blue bricks that get cleared along the wall

Please find the *Lemming-Arturito Excel Spreadsheet* in the Groups Folder and fill in this data for your robots behaviors. This will require you to partner up with other groups. For now let's not worry about making sure we manage to get results from all the different combinations of different groups.

Challenge # 1:

Can you program a Lemming or Arturito as a simple set of open ended reflexes as we did the Braitenberg Vehicles and the Didabots, or do we need to identify specific values (or maybe even specific conjunctions of sensor readings) to integrate the range of needed behaviors? What kinds of sensor values (stimulus properties) would you use to more discretely trigger each behavior?

Challenge #2: How would you program the Lemmings to avoid AVOIDing its conspecifics unless there was a collision was immanent? (We will talk about defining, recording, and calling on the variables the week of November 3rd).

Challenge #3: The original experiment was run in a room…but we have a low walled corral. The angle/placement of the top ultrasonic sensor will have to be gerrymandered to morphologically match our environment

Sample Program: Browse the groups folders to see how your colleagues in class have tackled these challenges and bootstrap your own solution. The general subsumption architecture I suggested for a solution (but have not tested) looks like this:

Level 3. BRICK SORTER
- $L1 < n_1$ = black brick
- $n_1 < L1 < n_2$ = white brick
- $L1 > n_2$ = no brick
- T = Top-SONAR
- B = Bottom-SONAR
- LEAVE BRICK = (leave the brick where it is)
  - motor A = -20
  - motor C = -10
  - wait1Msec (1000)
  - motor A = 10
  - motor C = 25
  - wait1Msec (750)
- DRAG BRICK = (turn & bring brick with you)
  - motor A = 20
  - motor C = 10
  - wait1Msec (1000)
- If WHITE BRICK then AVOID (leave the brick at a wall)
- If BLACK BRICK then LEAVE BRICK
  - LEAVE BRICK at white bricks
  - DRAG BRICK at walls

Level 2. BRICK CATCHER
- If $B < n_3$ then GOSTRAIGHT

Level 1. AVOID
- If $T < n_4$ then LEAVE BRICK

Level 0. GO-WANDER
- Run motors forward at some (SLOW!) speed with motorspeeds offset by 1% to generate a slight directional bias.

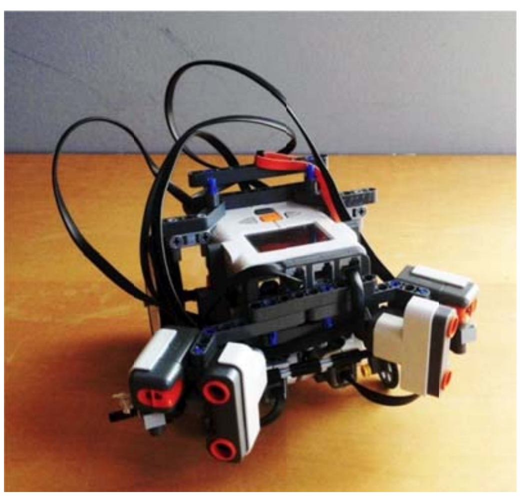
Exercise Set #4

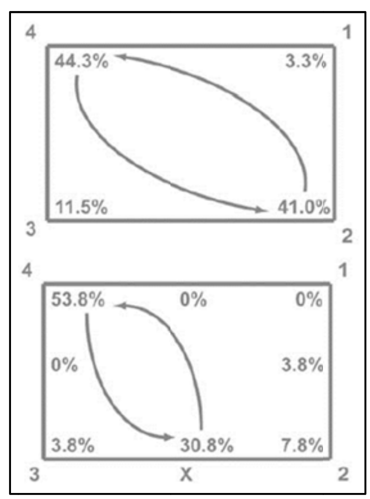
antiSLAM: Navigation, or the capacity for an organism to intentionally move around an environment to achieve its goals, seems to be a foundational capacity for intelligent systems. At minimum navigation requires an organism to be able to *locate* itself in an environment, *search* for (successfully locate) the position a goal location, and *plan a path* to the goal location using an evaluation process that exhibits *coverage* of all of the possible alternative paths. These processes have traditionally been thought to require *cognitive maps* or spatial representations of the layout of landmarks in the local environment.

antiSLAM is a purely reactive behavior based robot developed by Michael Dawson designed to replicate simple navigation behaviors exhibited by rats in a rectangular environment…but without the use of cognitive maps. During week 12 we will discuss the subsumption architecture employed in antiSLAM and examine its behavior in what is called *the reorientation task*. The antiSLAM robot exhibits a sensitivity to both geometric cues and feature cues in its environment. However, in the absence of feature cues to uniquely disambiguate them it cannot differentiate between geometrically identical landmarks, e.g. diagonally opposed corners in a rectangular environment. antiSLAM therefore exhibits *rotational errors* in its navigation behaviors, choosing each of a pair of diagonally opposed corners equally across trials rather than orienting to either one as its target goal.

The question, then, is whether antiSLAM has adequately located either itself or its goal location in determining its path through the environment.

Demo and discussion week 12





Exercise Set #5*

Toto (optional advanced project): Maja Mataric's (1991, 2006) TOTO provides an illustration of a *simultaneous localization and mapping (SLAM)* architecture. TOTO records its sensor values, the relative rotations of its two motors, and its compass direction as it moves through an environment. Stereotyped patterns in this data are then used to build a topological map of the relative positions of landmarks in its environment, e.g. a straight compass heading paired with a close left sonar reading for a number of motor rotations = a Left Wall of a specific length which is *next to* a corridor and across from a *messy area*.

We will discuss TOTO as an intermediate solution to the problem of navigation that lies somewhere between view independent metric cognitive maps and a anti-representationalist, embodied strategy employed in antiSLAM.

Toto's landmark detection layer

```
my-behavior-type:  C
my-compass-direction:  0
my-approximate-location:  (x,y)
my-approximate-length:  6.5
whenever received (input)
  if input(behavior-type) = my-behavior-type
    and
  input(compass-direction) = my-compass-direction
  then
    active <- true
```

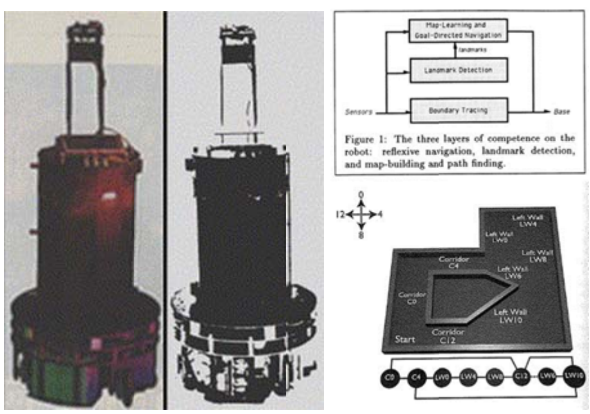


Figure 1: The three layers of competence on the robot: reflexive navigation, landmark detection, and map-building and path finding.

Maja J. Mataric, *The Robotics Primer* (Cambridge, MA: MIT Press, 2006), 197, 201.