



Modern Robotics: Evolutionary Robotics

COSC 4560 / COSC 5560

Professor Cheney
1/22/18

This course is based off of
popular courses designed by:

Josh Bongard at the University of Vermont,
Jeff Clune at the University of Wyoming,
Hod Lipson at Cornell University

and adapted with the help of
Joost Huizinga (our awesome TA!)

Many thanks to all of the above
for making this possible!

What's this all about?



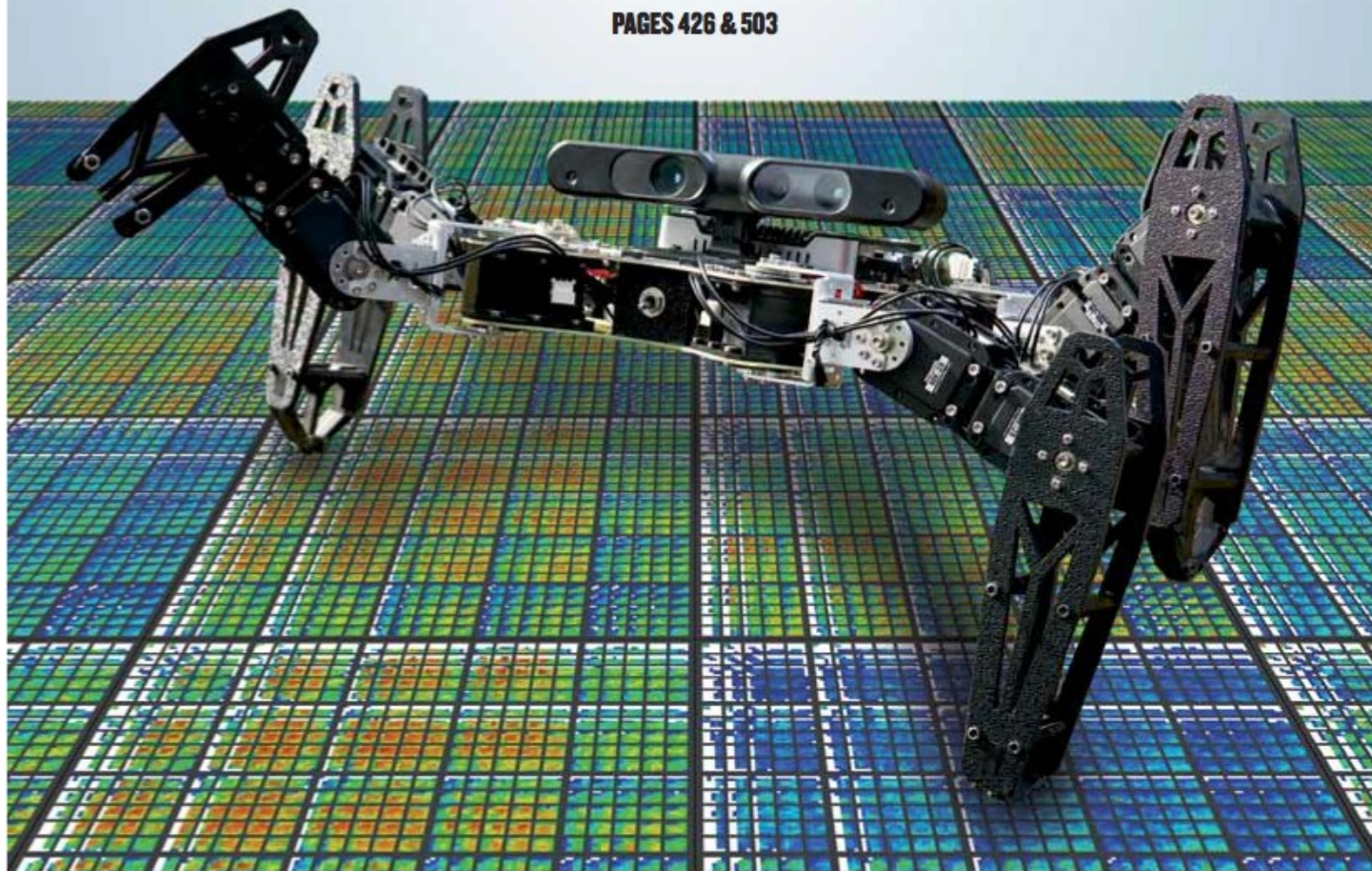
nature

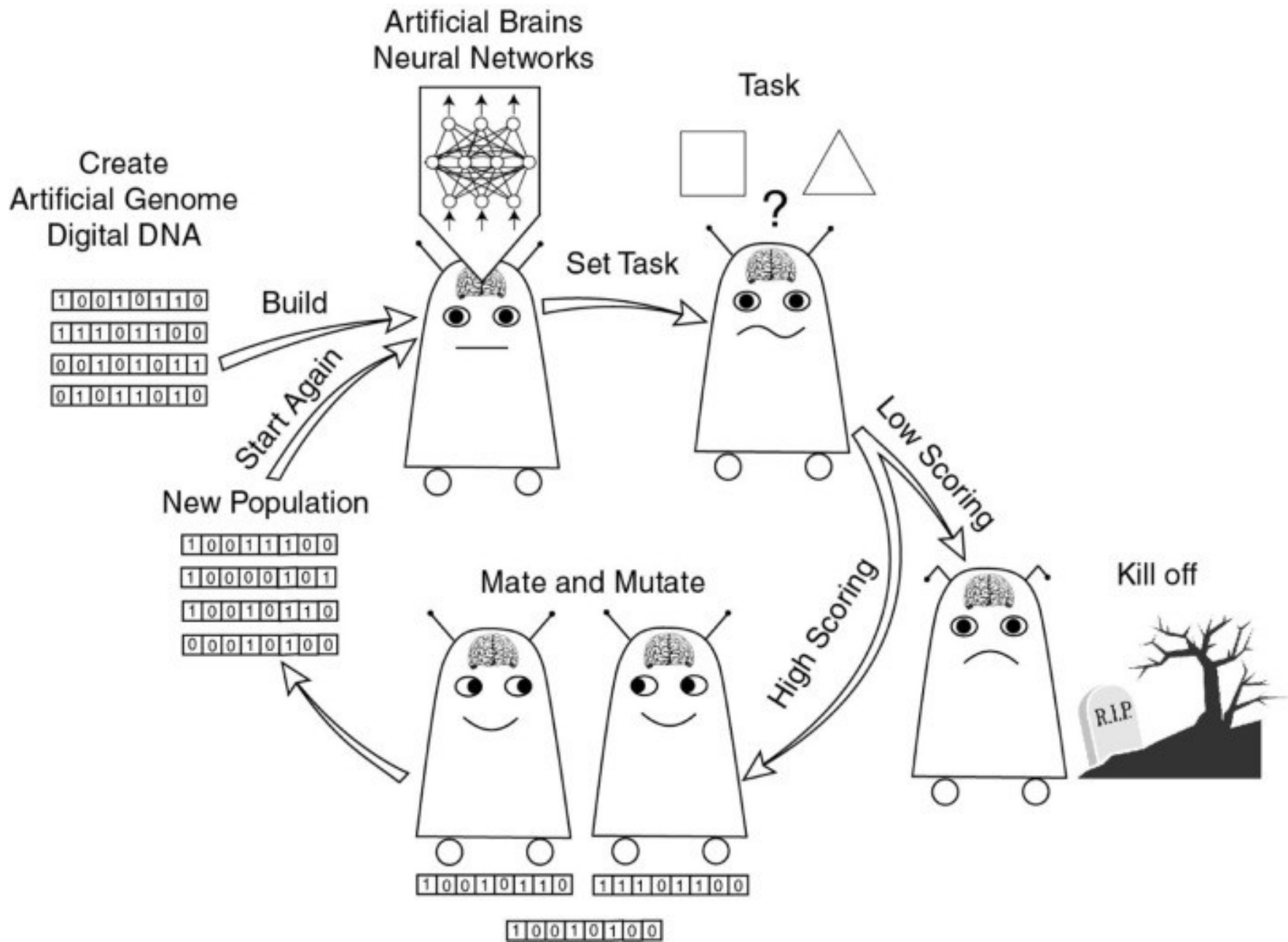
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

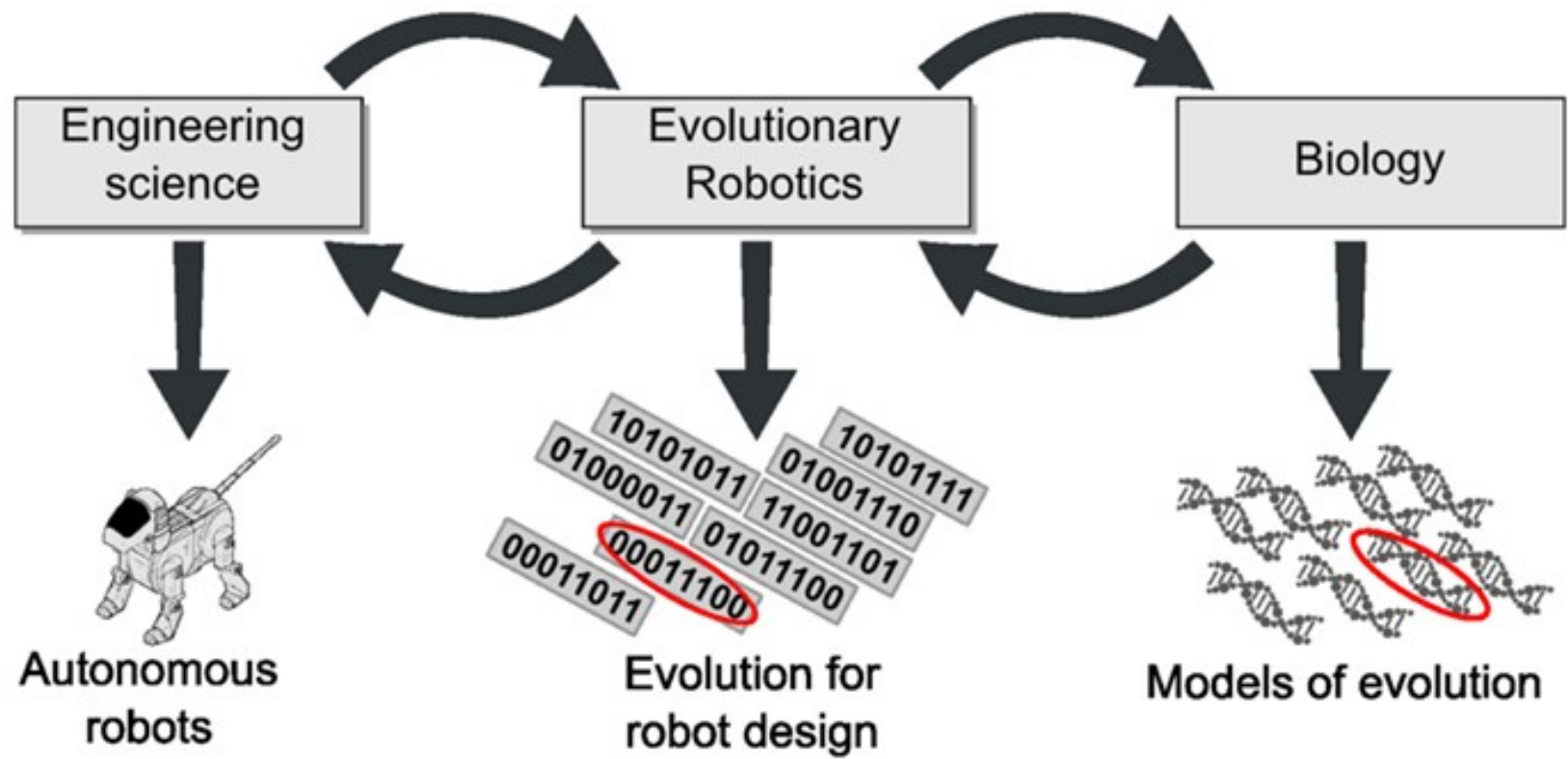
Back on its feet

Using an intelligent trial-and-error learning algorithm this robot adapts to injury in minutes

PAGES 426 & 503







Evolved Virtual Creatures

Karl Sims

Course Contents

Week 1: Intro and Motivation

- Big Picture... Why?

Week 2-3: Methods and Optimization

- Evolutionary Computation
- Neural Networks for Robotic Control

Week 4-6: Embodied Agents

- Embodied Cognition and Body-Plan Optimization
- Pattern Formation and Genetic Encodings

Week 7: Advanced Optimization

- Exploration vs. Exploitation

Week 8-12: State of the Art in Evolutionary Robotics

- Evolution and Development
- Multi-Agent Systems
- Active Learning

--- ***PROJECT PROPOSAL PITCHES*** ---

Week 13-14: Reinforcement Learning for Robotics

- Deep Reinforcement Learning

Week 15-16: Open Problems

- Real World Uses and Pitfalls

--- ***PROJECT VIDEO PRESENTATIONS*** ---

Course Website:

ncheney.com/teaching/robotics

Homework Assignments

Hands-on Implementation of concepts we learn in class

Learn by doing!¹

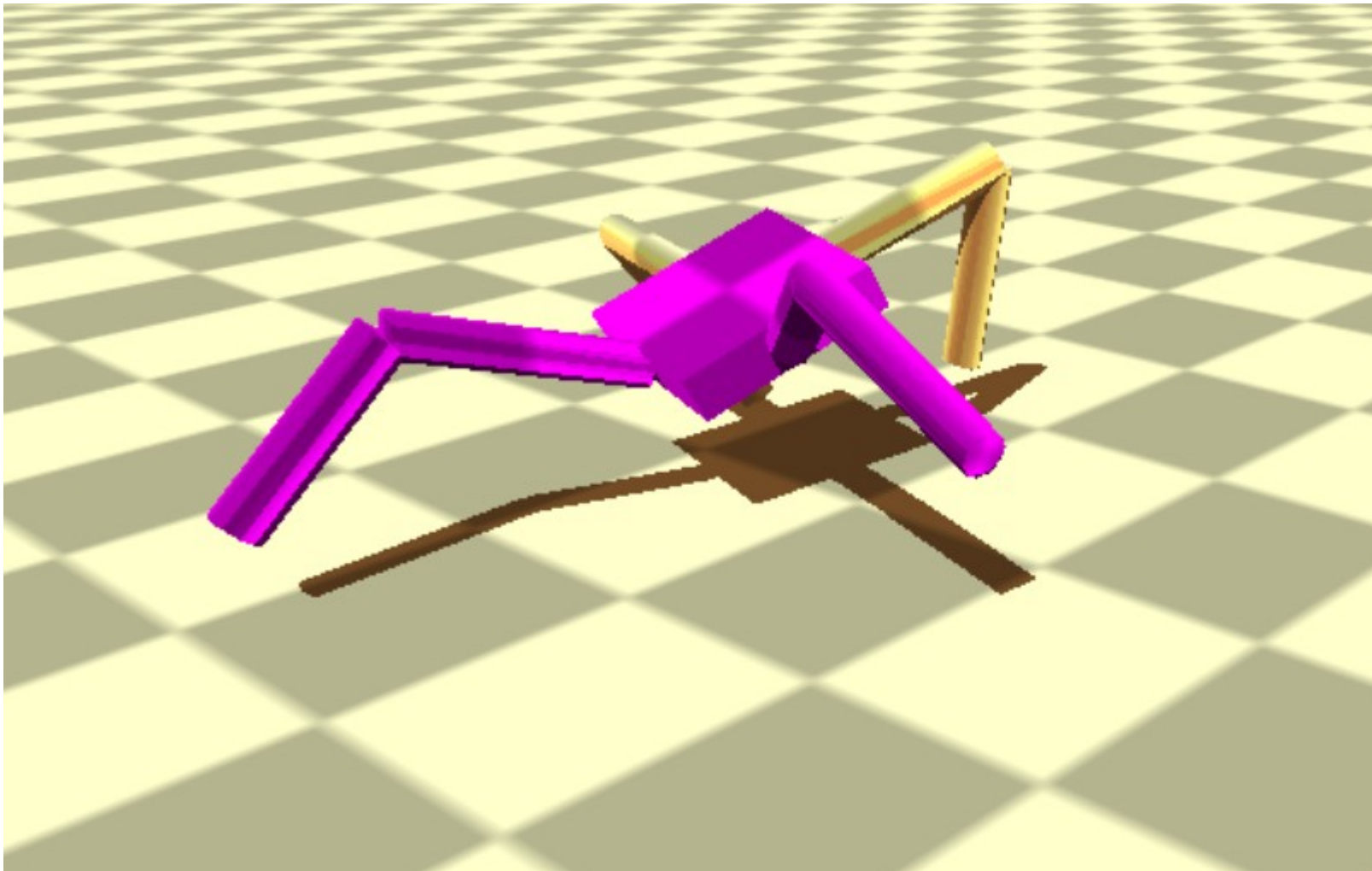
Programming in C++ and (visualizations in) Python (due every week)

- [1] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410-8415.

Over 8 weeks of assignments, you'll build a toolkit for conducting evolutionary robotics experiments!

As each assignment adds a new piece to your system, they are cumulative and build on your previous code

This means you'll still have to make up any you don't turn in on time (so turn them all in on time!)



Posted ahead of time – start early!

Really... start early!

Piazza is a great place to ask clarifying/high-level questions
(not to ask for solutions...)

Joost will be available to help answer questions
(both on Piazza, and during office hours)

Course Project

You'll use the experimental platform you've made
(or some other Evolutionary Robotics platform...)
to conduct a brand new experiment
(e.g. new algorithm, environment, task, etc.)

The goal is to create publication quality work
(class projects have gone on to be published before,
and that should be your goal too!)

This project will start with a proposal (written)
and a pitch (presentation) that demonstrates
your knowledge of the field of Evolutionary Robotics
(based on readings and lectures),
and makes a case for why your project
is new and interesting

The final project will be a YouTube video that you share
with your classmates (and with the world!)
showing off and explaining what you accomplished

Projects are meant to be done individually or in small groups
(Groups of two or three are held to a standard of
two or three times the work and results –
which is not easy to do! Be warned!)

If pursuing a group project, you'll also have to demonstrate
that each member did their share of work
for both the proposal and the video
(i.e. the same as an individual project)

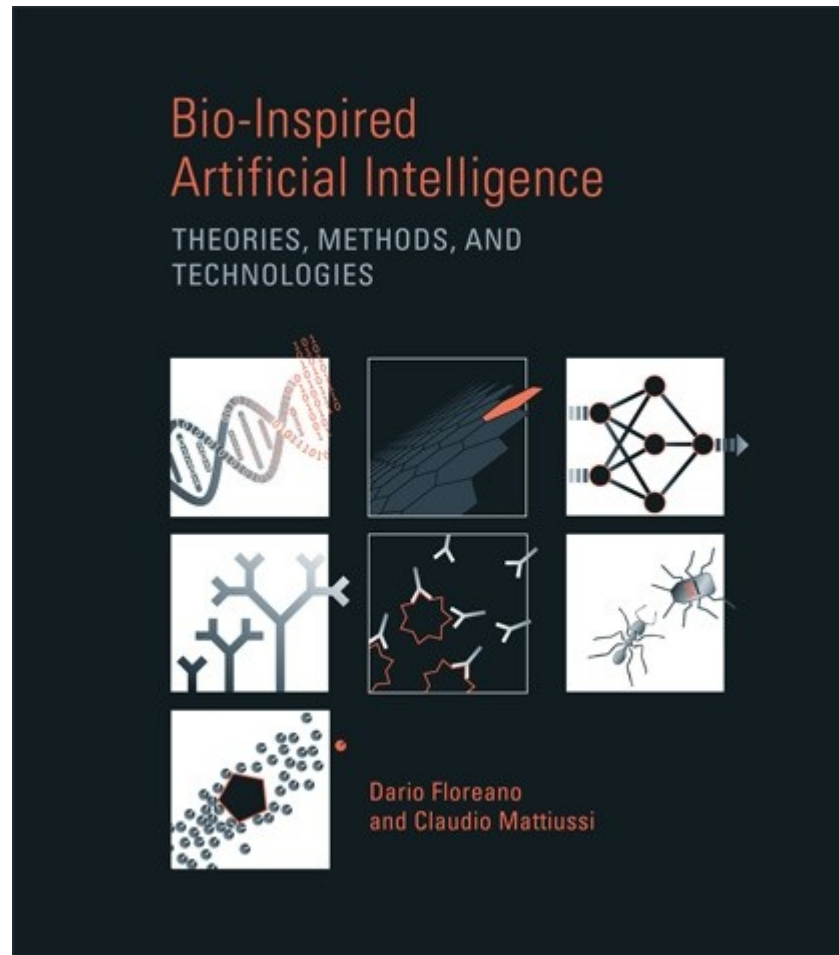
Textbook

Required:

Bio-Inspired Artificial Intelligence

Theories, Methods, and Technologies

By [Dario Floreano](#) and [Claudio Mattiussi](#)

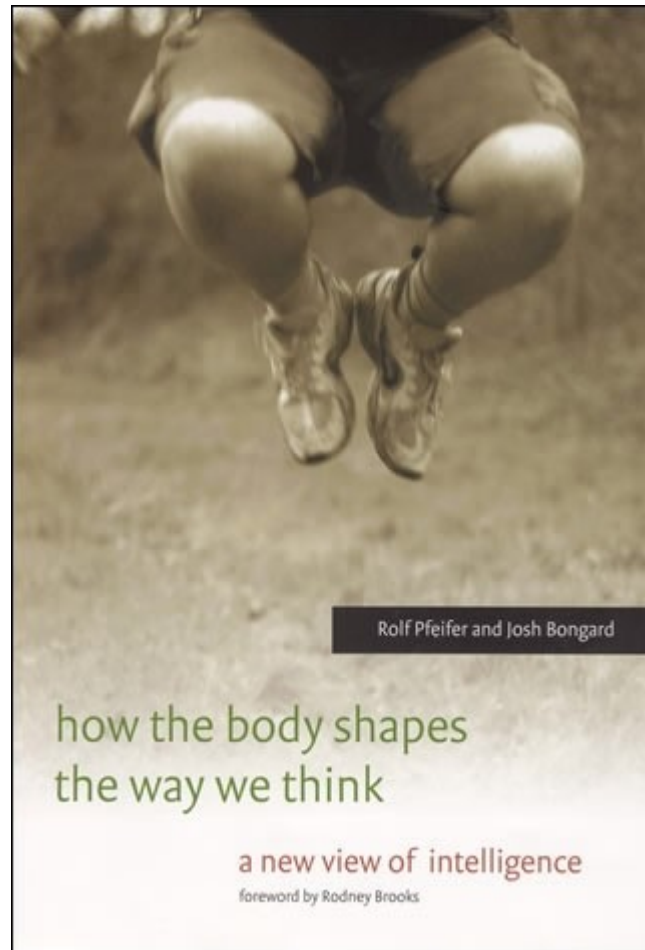


Optional:

How the Body Shapes the Way We Think

A New View of Intelligence

By [Rolf Pfeifer](#) and [Josh Bongard](#)



Papers:

Both foundational and state-of-the-art
(pdfs will be provided on course website)



Cornell University
Library

We gratefully acknowledge support from
the Simons Foundation
and member institutions

arXiv.org

Logged in as [nickcheney](#) | [My Account](#) | [Logout](#)

[\(Help\)](#) | [Advanced search](#)

Open access to 1,349,584 e-prints in Physics, Mathematics, Computer Science, Quantitative Biology, Quantitative Finance, Statistics, Electrical Engineering and Systems Science, and Economics

Subject search and browse:

02 Jan 2018: [1991-2017 submission rate statistics](#) are now available.
See cumulative ["What's New"](#) pages. Read [robots beware](#) before attempting any automated download

Physics

- **Astrophysics** ([astro-ph](#) [new](#), [recent](#), [find](#))
includes: Astrophysics of Galaxies; Cosmology and Nongalactic Astrophysics; Earth and Planetary Astrophysics; High Energy Astrophysical Phenomena; Instrumentation and Methods for Astrophysics; Solar and Stellar Astrophysics
- **Condensed Matter** ([cond-mat](#) [new](#), [recent](#), [find](#))
includes: Disordered Systems and Neural Networks; Materials Science; Mesoscale and Nanoscale Physics; Other Condensed Matter; Quantum Gases; Soft Condensed Matter; Statistical Mechanics; Strongly Correlated Electrons; Superconductivity
- **General Relativity and Quantum Cosmology** ([gr-qc](#) [new](#), [recent](#), [find](#))
- **High Energy Physics - Experiment** ([hep-ex](#) [new](#), [recent](#), [find](#))
- **High Energy Physics - Lattice** ([hep-lat](#) [new](#), [recent](#), [find](#))
- **High Energy Physics - Phenomenology** ([hep-ph](#) [new](#), [recent](#), [find](#))
- **High Energy Physics - Theory** ([hep-th](#) [new](#), [recent](#), [find](#))
- **Mathematical Physics** ([math-ph](#) [new](#), [recent](#), [find](#))
- **Nonlinear Sciences** ([nlin](#) [new](#), [recent](#), [find](#))
includes: Adaptation and Self-Organizing Systems; Cellular Automata and Lattice Gases; Chaotic Dynamics; Exactly Solvable and Integrable Systems; Pattern Formation and Solitons
- **Nuclear Experiment** ([nucl-ex](#) [new](#), [recent](#), [find](#))
- **Nuclear Theory** ([nucl-th](#) [new](#), [recent](#), [find](#))
- **Physics** ([physics](#) [new](#), [recent](#), [find](#))
includes: Accelerator Physics; Applied Physics; Atmospheric and Oceanic Physics; Atomic Physics; Atomic and Molecular Clusters; Biological Physics; Chemical Physics; Classical Physics; Computational Physics; Data Analysis, Statistics and Probability; Fluid Dynamics; General Physics; Geophysics; History and Philosophy of Physics; Instrumentation and Detectors; Medical Physics; Optics; Physics Education; Physics and Society; Plasma Physics; Popular Physics; Space Physics
- **Quantum Physics** ([quant-ph](#) [new](#), [recent](#), [find](#))

Mathematics

- **Mathematics** ([math](#) [new](#), [recent](#), [find](#))
includes (see detailed description): Algebraic Geometry; Algebraic Topology; Analysis of PDEs; Category Theory; Classical Analysis and ODEs; Combinatorics; Commutative Algebra; Complex Variables; Differential Geometry; Dynamical Systems; Functional Analysis; General Mathematics; General Topology; Geometric Topology; Group Theory; History and Overview; Information Theory; K-Theory and Homology; Logic; Mathematical Physics; Metric Geometry; Number Theory; Numerical Analysis; Operator Algebras; Optimization and Control; Probability; Quantum Algebra; Representation Theory; Rings and Algebras; Spectral Theory; Statistics Theory; Symplectic Geometry

Computer Science

- **Computing Research Repository** ([CoRR](#) [new](#), [recent](#), [find](#))
includes (see detailed description): Artificial Intelligence; Computation and Language; Computational Complexity; Computational Engineering, Finance, and Science; Computational Geometry; Computer Science and Game Theory; Computer Vision and Pattern Recognition; Computers and Society; Cryptography and Security; Data Structures and Algorithms; Databases; Digital Libraries; Discrete Mathematics; Distributed, Parallel, and Cluster Computing; Emerging Technologies; Formal Languages and Automata Theory; General Literature; Graphics; Hardware Architecture; Human-Computer Interaction; Information Retrieval; Information Theory; Learning; Logic in Computer Science; Mathematical Software; Multiagent Systems; Multimedia; Networking and Internet Architecture; Neural and Evolutionary Computing; Numerical Analysis; Operating Systems; Other Computer Science; Performance; Programming Languages; Robotics; Social and Information Networks; Software Engineering; Sound; Symbolic Computation; Systems and Control

Quantitative Biology

- **Quantitative Biology** ([q-bio](#) [new](#), [recent](#), [find](#))
includes (see detailed description): Biomolecules; Cell Behavior; Genomics; Molecular Networks; Neurons and Cognition; Other Quantitative Biology; Populations and Evolution; Quantitative Methods; Subcellular Processes; Tissues and Organs

Reading will be posted on course website:

ncheney.com/teaching/robotics

Schedule will be updated regularly
check back often!

Read **before** class!!!

Some of the material will be covered in class
(read it anyways!)

Some will not be covered during the lectures,
but still important and helpful for assignments and projects

Read **before** class!!!

The reading will be focused heavily on important
and state-of-the-art topics in the field

Knowing both the topics in the scientific literature and how
to deconstruction and interpret scientific papers are an
enormous part of being an AI researcher/scientist/engineer

Read **before** class!!!

But actually.... do it!

Graduate students will be required to hand in paper reactions (not summaries!) at the end of each week describing their thoughts on the readings

Undergraduates with aspirations for research-related careers (e.g. graduate school, AI engineer/scientist) are encouraged to also hand in weekly paper reactions for extra credit!

Lecture Slides

Link to pdfs will be posted on the course website

ncheney.com/teaching/robotics

within a day or two after class
(let me know if I'm being slow...)

Grading

40-50% – Homework Assignments, learn by doing!

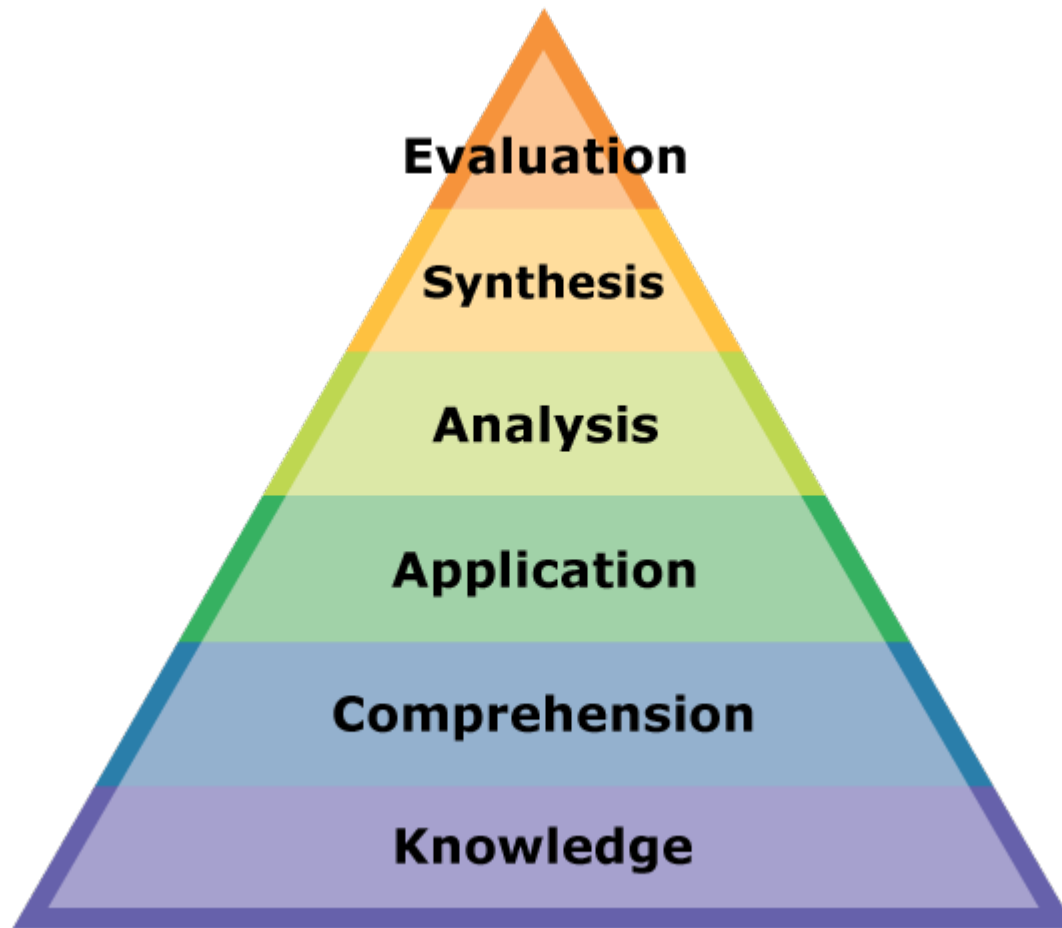
0-10% – Paper Reactions, from readings

15% – Project Proposals (including background from readings)

30% – Course Project (final), hands on research project

5% – Participation (involvement in class discussions, Piazza, ...)

Bloom's Taxonomy



Participation

Part of being an AI researcher is being involved
in an active community of discussion

Class should be a discussion with lots of feedback
(you and I get rare feedback on learning from exams/grades)

The Piazza online forum is a great way to earn participation credit outside of class times

Earn credit for both asking and answering questions to/from your classmates

<http://www.piazza.com/uwyo/spring2018/cosc4560cosc5560>

This is also a huge part of being an AI researcher!
(e.g. Stack Exchange)

Attendance is also a part of participation grades

Expectation is that you will attend all lectures
(I'll try to make it that you really want to also!)

For exam/project presentations,
only University Excused Absences are excepted
(you can get these from the Dean of Students)

Additional accommodations (including taking exams at the Disability Support Services office) are available for any students with physical/learning/psychological disabilities

Please first contact the DSS office
(again with the Dean of Students)
And they will work with me to arrange
the necessary accommodations

Laptops and smartphones are not allowed in class
(this is also part of your participation grade)

Leads to worse overall learning outcomes¹
(distracting for you, distracting for others
around/behind you, distracting for me)

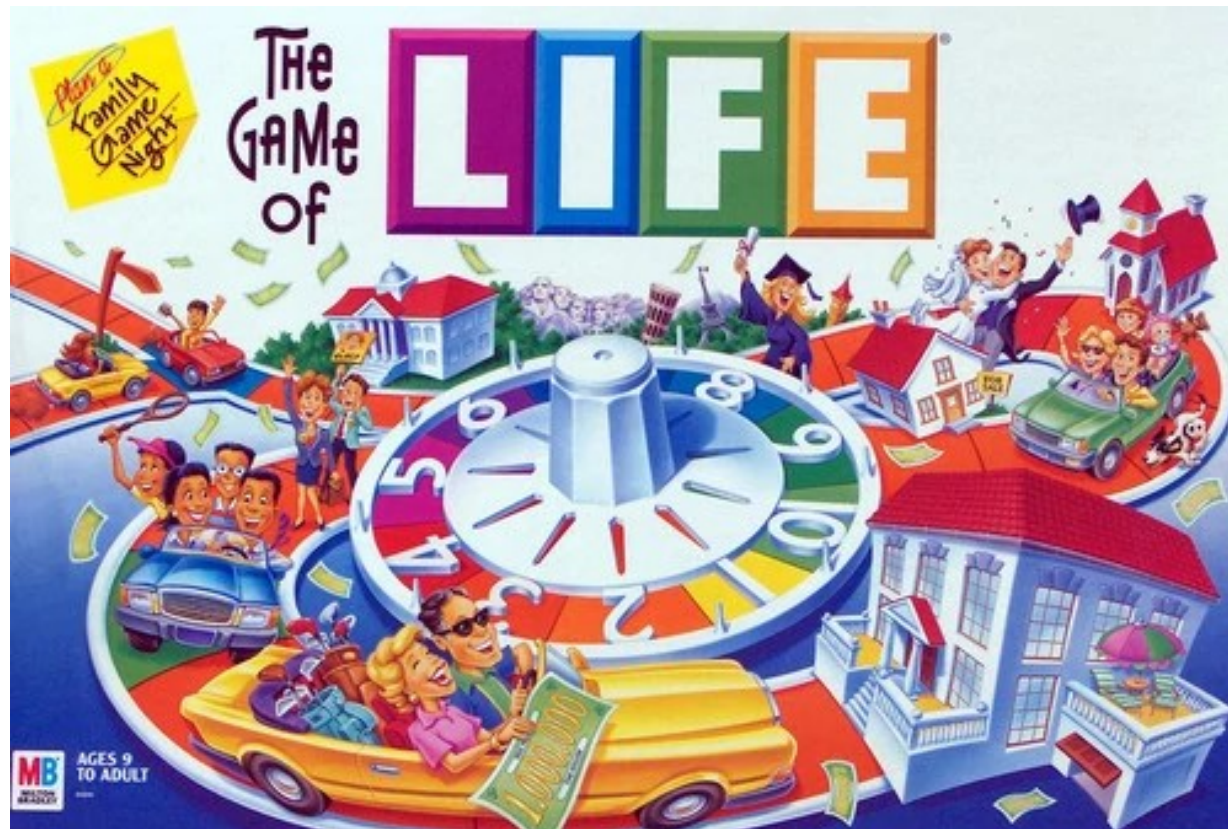


Please bring a pen and paper for in-class exercises
You do not need to bring your textbook

[1] Sana, F., Weston, T., & Cepeda, N. J. (2013). Laptop multitasking hinders classroom learning for both users and nearby peers. *Computers & Education*, 62, 24-31.

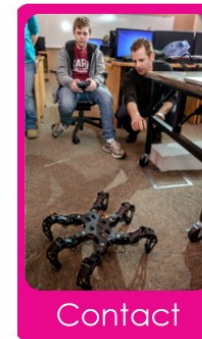
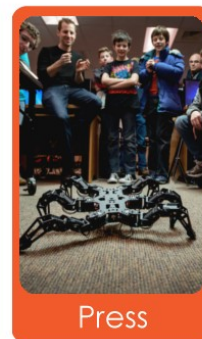
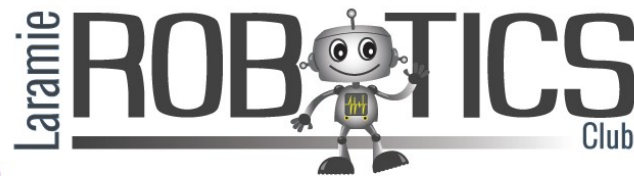
Participation Extra Credit:

(+1) come to office hours so I can get to know!
(I can only help you to achieve your goals if I know them)



Participation Extra Credit:

(+1) volunteer at the Laramie Robotics Club with us!
(teach middle schoolers about programming and robotics)



Come have fun playing with robots! It's free!


Every week during the school year middle school and high school students learn robotics with University of Wyoming professors and graduate students.

Join the fun!



Participation Extra Credit:

(+1) be curious and share your findings with the class!
(make a slide or two from something you saw in class or in the news and did extra research on)

 Cornell University Library

We gratefully acknowledge support from the Simons Foundation and member institutions

arXiv.org > cs > cs.CV

Search or Article ID inside arXiv All papers

Broaden your search using Semantic Scholar

[Help](#) | [Advanced search](#)

Computer Vision and Pattern Recognition

Authors and titles for recent submissions

- [Wed, 30 Aug 2017](#)
- [Tue, 29 Aug 2017](#)
- [Mon, 28 Aug 2017](#)
- [Fri, 25 Aug 2017](#)
- [Thu, 24 Aug 2017](#)

[total of 93 entries: 1-25 | 26-50 | 51-75 | 76-93]
[showing 25 entries per page: fewer | more | all]

Wed, 30 Aug 2017

[1] [arXiv:1708.08874](#) [[pdf](#), [other](#)]
Reasoning about Fine-grained Attribute Phrases using Reference Games
[Jong-Chyi Su](#), [Chenyun Wu](#), [Huatzu Jiang](#), [Subhransu Maji](#)
Comments: To appear in ICCV 2017
Subjects: [Computer Vision and Pattern Recognition \(cs.CV\)](#)

[2] [arXiv:1708.08844](#) [[pdf](#), [other](#)]
Semantic Texture for Robust Dense Tracking
[Jan Czarowski](#), [Stefan Leutenegger](#), [Andrew Davison](#)
Subjects: [Computer Vision and Pattern Recognition \(cs.CV\)](#)

[3] [arXiv:1708.08825](#) [[pdf](#)]
4D Multi-atlas Label Fusion using Longitudinal Images
[Yuankai Huo](#), [Susan M. Resnick](#), [Bennett A. Landman](#)
Subjects: [Computer Vision and Pattern Recognition \(cs.CV\)](#)

[4] [arXiv:1708.08754](#) [[pdf](#), [other](#)]
Autoencoder with recurrent neural networks for video forgery detection
[Dario D'Avino](#), [Davide Cozzolino](#), [Giovanni Poggi](#), [Luisa Verdoliva](#)
Comments: Presented at IS&T Electronic Imaging: Media Watermarking, Security, and Forensics, January 2017
Subjects: [Computer Vision and Pattern Recognition \(cs.CV\)](#)

[5] [arXiv:1708.08732](#) [[pdf](#), [ps](#), [other](#)]
Multi-view Low-rank Sparse Subspace Clustering
[Maria Brbic](#), [Ivica Kopriva](#)
Subjects: [Computer Vision and Pattern Recognition \(cs.CV\)](#); [Learning \(cs.LG\)](#); [Optimization and Control \(math.OC\)](#); [Machine Learning \(stat.ML\)](#)

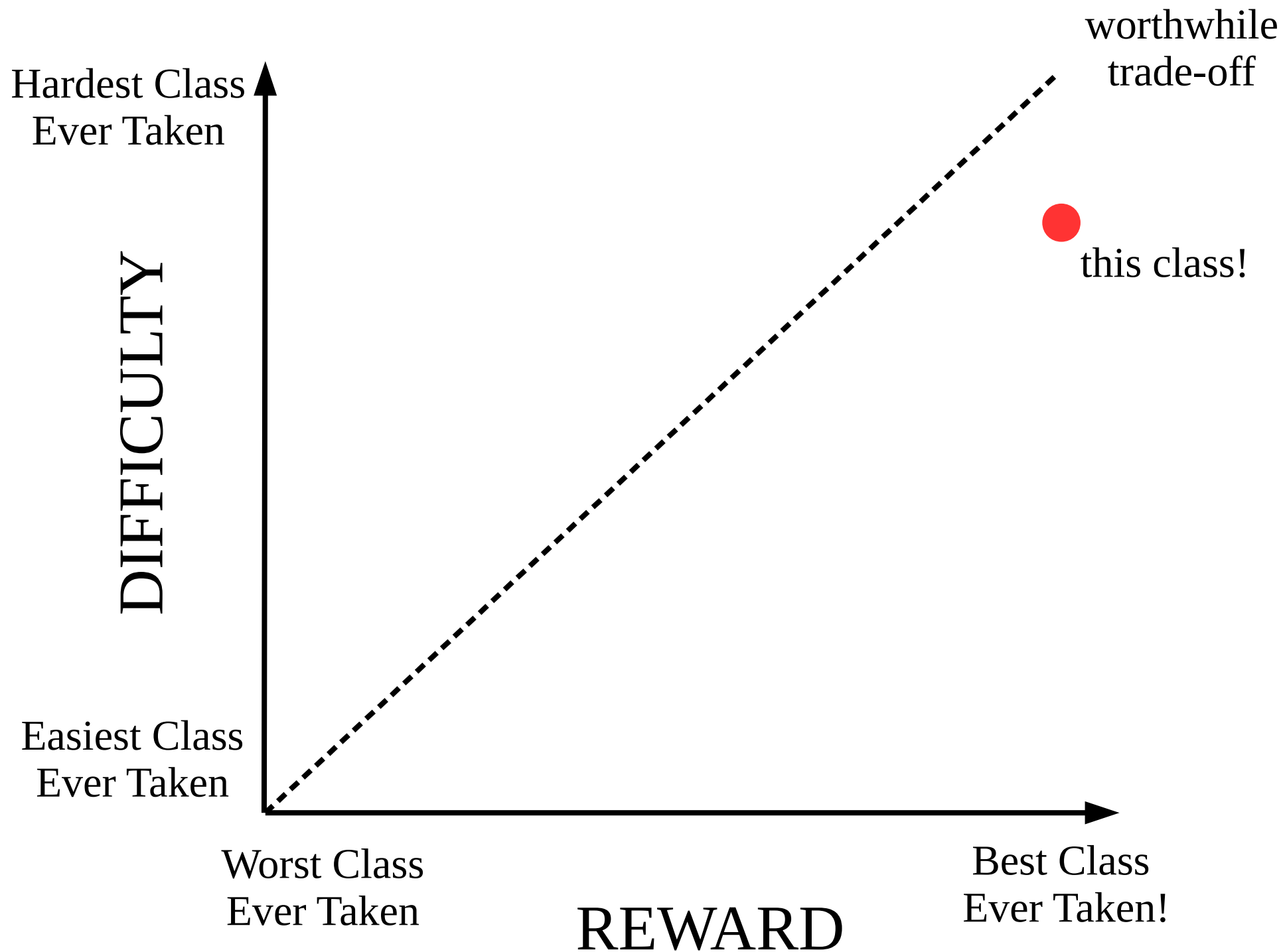
[6] [arXiv:1708.08728](#) [[pdf](#), [other](#)]
Curriculum Learning for Multi-Task Classification of Visual Attributes
[Mikaela Saeed](#), [Benjamin Ghorokh](#), [Christophoros Nikou](#), [Jenssen A. Kalogeridis](#)

There is a lot to cover!

This class will be a lot of work – it's going to be hard!

Lots of reading, lots of coding

But it will be totally worth it, and you will learn a lot!



Feedback

Please let me know how you feel about the class
(e.g. too fast/slow, not enough/too much time
on a given concept, good/bad application examples)

Tell me: after/before/during class
mid-term survey
office hours
email (including anonymous email)

I will strongly consider your feedback
(good chance I will implement it in some way)

Office hours:

(lectures, readings, project brainstorming, life stuff)

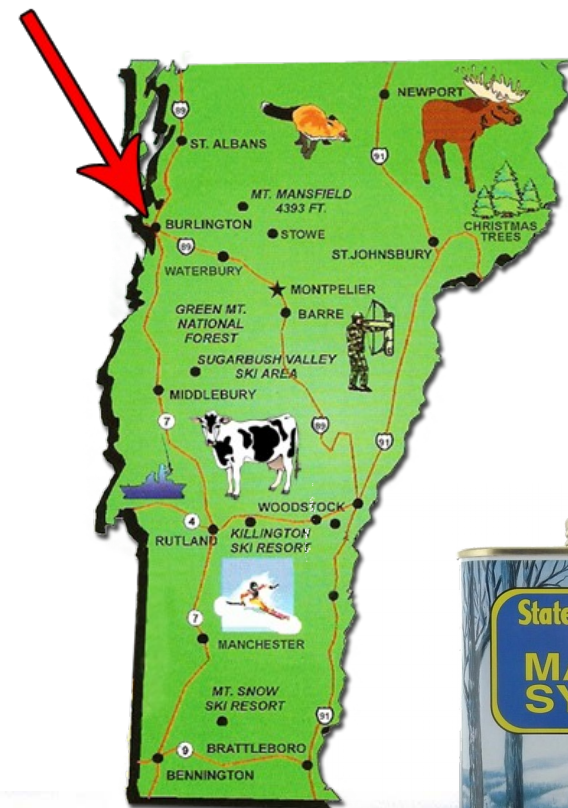
By appointment – ncheney@uwyo.edu

TA office hours:

(coding help and assignments)

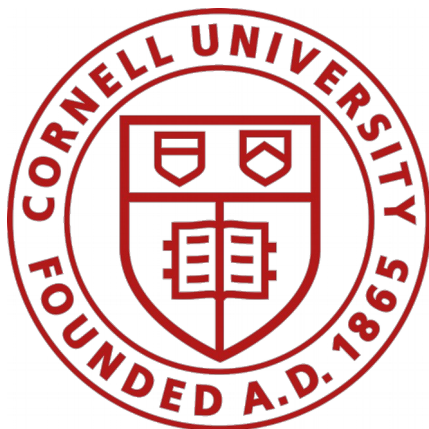
TBD – to be posted on course website

Meet and Greet

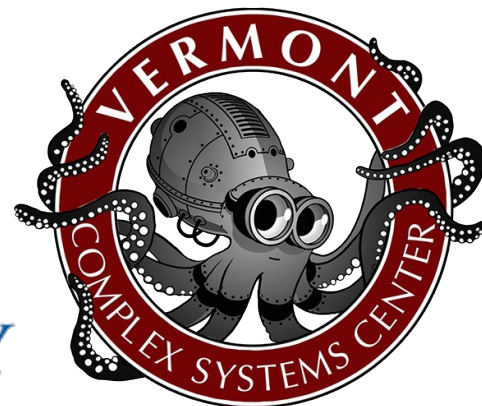




The University
of Vermont



COLUMBIA
UNIVERSITY



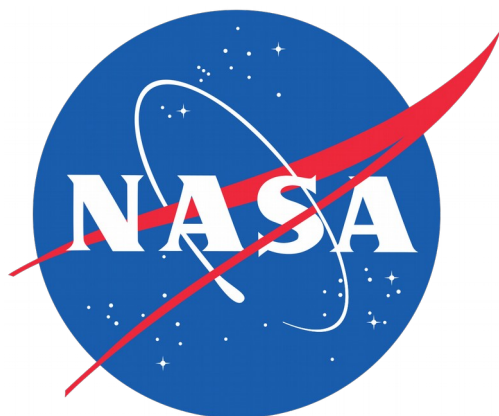
UNIVERSITY
OF WYOMING

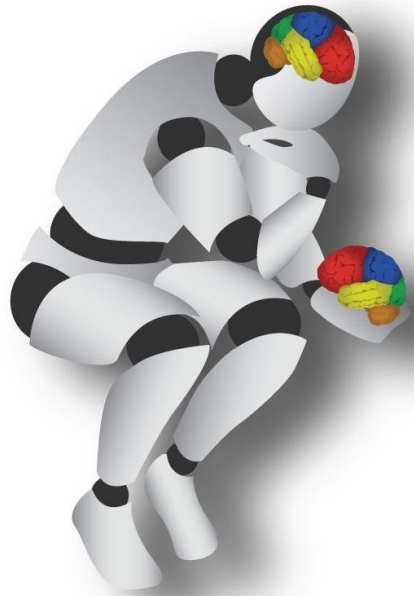


UBER
AI Labs



SANTA FE
INSTITUTE





EVOLVING
ARTIFICIAL
INTELLIGENCE
LABORATORY



Build robots
that rival animals



**CREATIVE MACHINES LAB
COLUMBIA UNIVERSITY**

Build robots that
create and are creative





And you... ?

What's your name?

Where are you from?

Why are you here?
(What's your background/major?
What are you hoping to learn?)

One fun fact about yourself