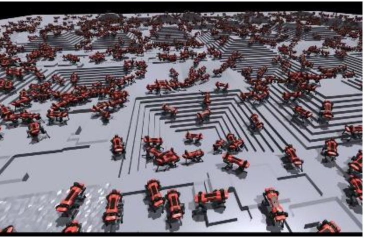
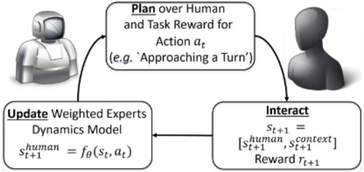
EC518: Robot Learning

(and Vision for Navigation)



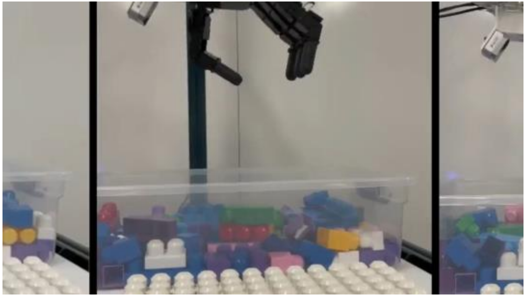
Eshed Ohn-Bar



Sep. 6, 2023

Robot Systems Today

Robot Systems Today



Robot Systems "In the Wild"

Robot Systems "In the Wild"

Robot Systems “In the Wild”

Goal: How can we design robotic systems that robustly operate in complex, dynamic, and uncertain real-world environments?

- How to formulate learning algorithms for general robotics and sensori-motor navigation
- Explore challenges in perception-based control pipelines
- Affordance-based and goal-directed representation of semantic scene, motion, and geometry
- Limitations (and complementarity) of reinforcement, inverse reinforcement, and imitation learning approaches
- Policy optimization (e.g., model-based vs. model-free) and sample efficiency analysis
- Multi-modal algorithms for multi-sensor (camera, LIDAR and radar perception) and multi-task learning
- Human-in-the-loop and social learning
- Reading and presenting recent research papers
- Participation in a competition to put these ideas to the test (for awards and fame)

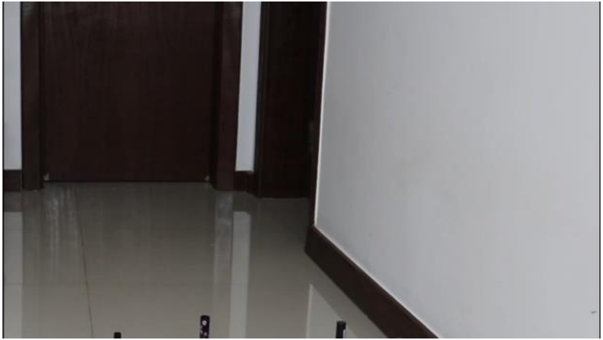
Overarching Objective for the Class

- Holistic understanding of ***fundamental paradigms and challenges*** in learning-based autonomous systems.

- Formulation of in-depth, critical analysis and communication of key concepts, terminology, ***state-of-the-art research approaches*** robotics

We must perceive in order to move, but we must also move in order to perceive
- Gibson (1979)

Why Navigation?



"**Come to Massachusetts** to test your cars, we have bad roads, worse weather, even worse drivers,"

- Transportation Secretary Stephanie Pollack

GO BOSTON 2030

Imagining Our Transportation Future

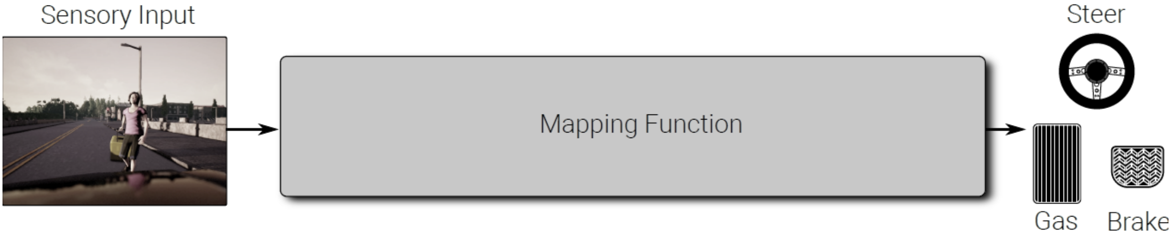
World Health Organization

Death from car accident

~ one person every 25 seconds

Robot Learning and Vision for Navigation

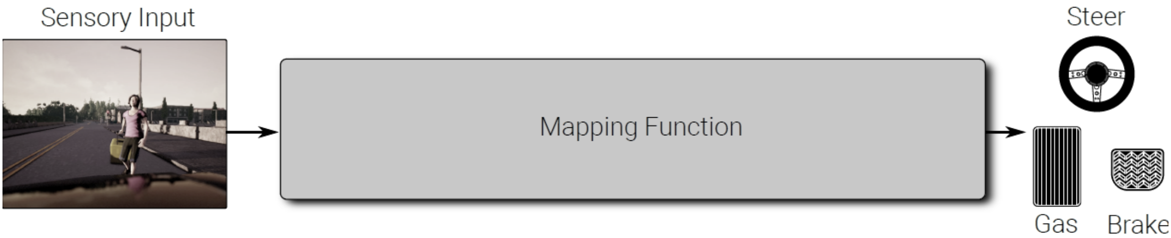
Robot Learning and Vision for Navigation



- Massive technological challenge, ***real-world applications*** in safety and assistive technologies

- Embodied intelligence, system can ***act and move***

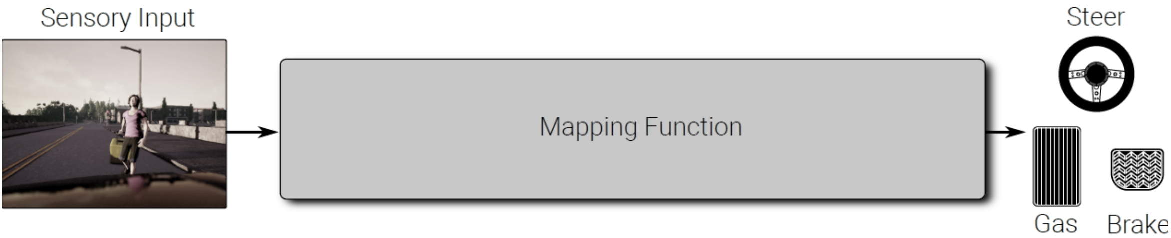
Robot Learning and ***Vision*** for Navigation



- How to code this?

If Pedestrian then
Slow down
If Traffic Light is Red then Stop
…

Robot Learning and ***Vision*** for Navigation



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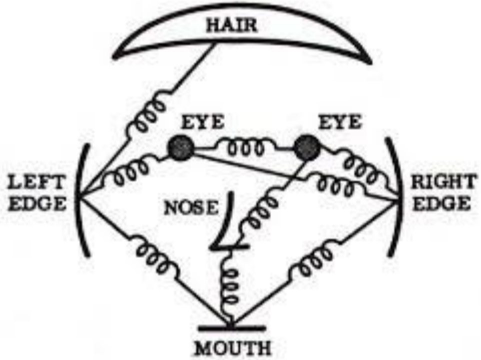
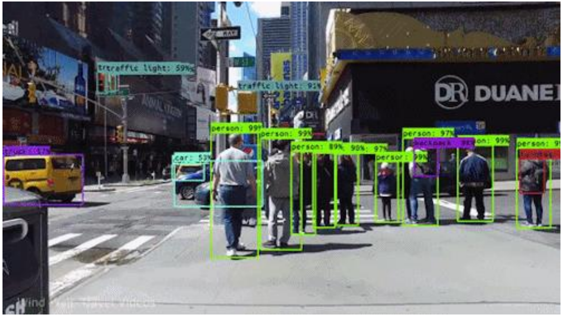
157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

Computer Vision – Then and Now

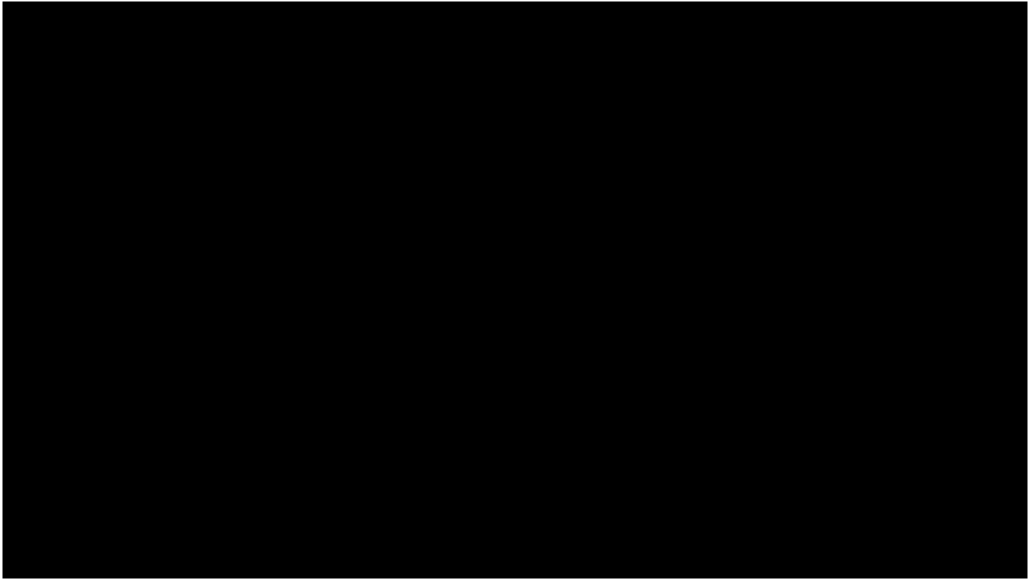




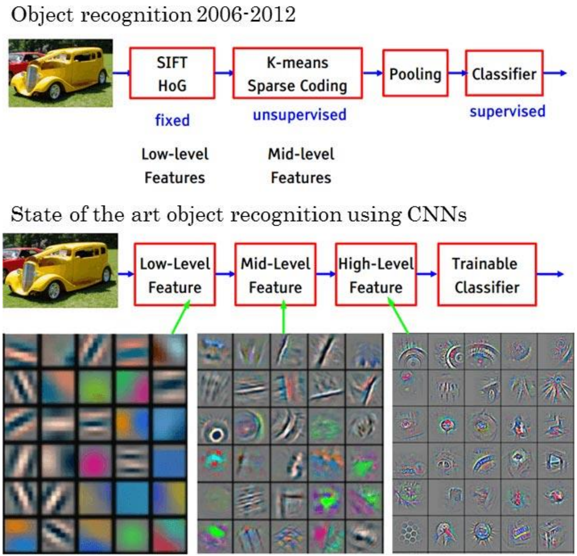
Geometry and deformable parts, object detection

Models/Metrics Are Auxiliary to the Task!

Accident with Uber Vehicle

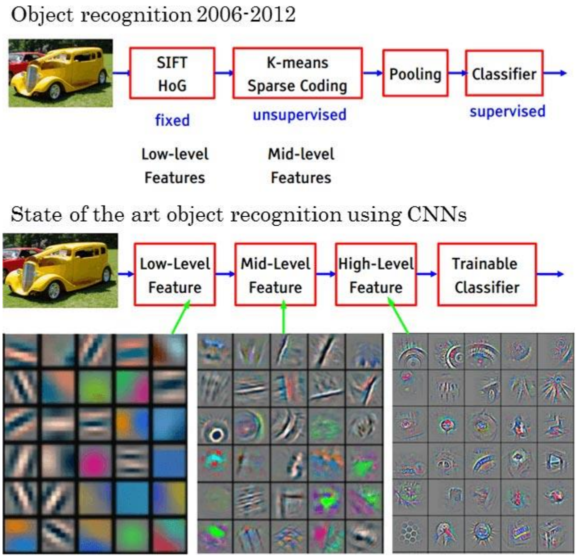


Computer Vision – Then and Now



Taken from Y. LeCunn

Computer Vision – Then and Now



- What should be the ***output***?
- What supervision?
- Complex tasks?
- Agent is passive

Taken from Y. LeCunn

On the Importance of Embodied Intelligence

Which of the Surrounding Agents are More Important?

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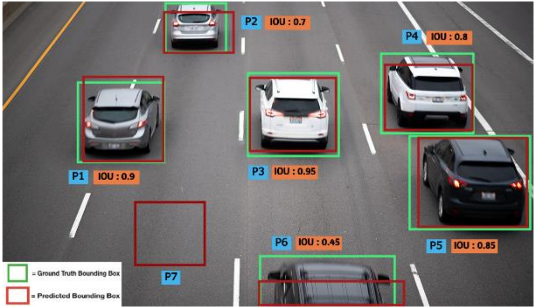
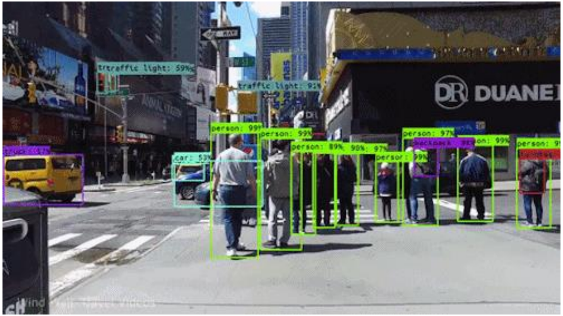
Computer Vision – Not Optimizing for the Right Thing!

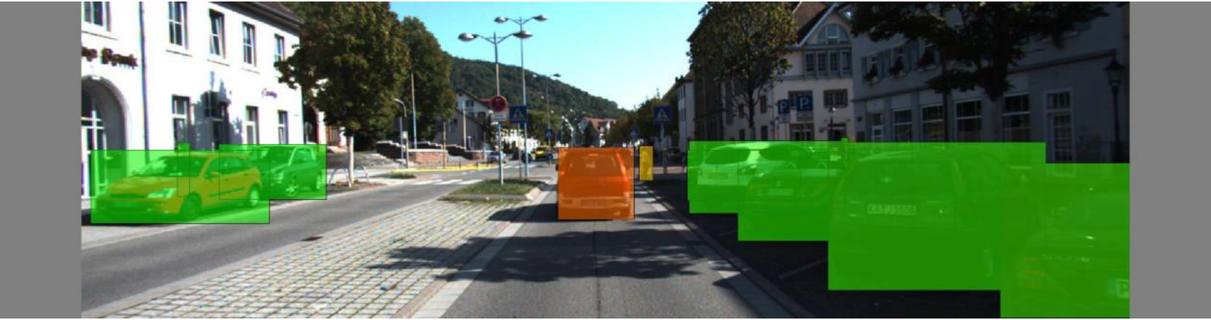




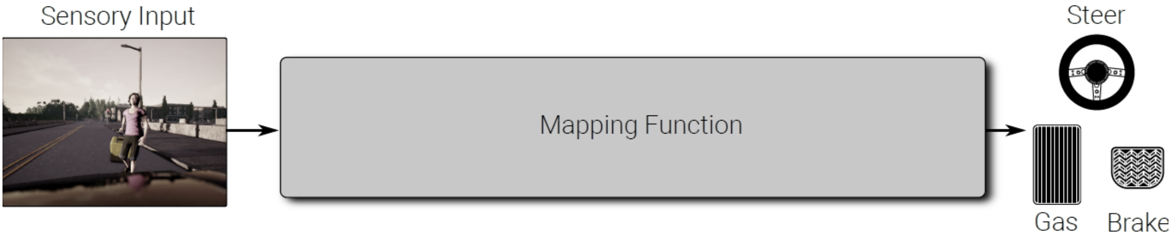
Modeling, Training, Evaluation Should Consider Navigation Task

Color coded from high to moderate to low importance

Ohn-Bar et. al, ICPR 2016, Pattern Recognition 2017



Robot Learning and Vision for Navigation



- Massive technological challenge, ***real-world applications*** in safety and assistive technologies

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Robot Learning and Vision for Navigation

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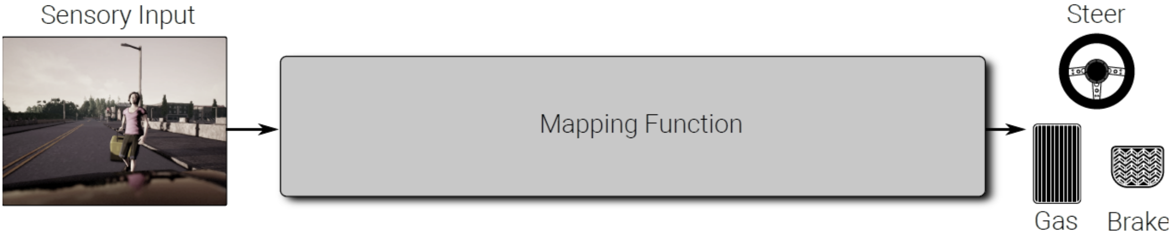
Learning for Autonomous Navigation

Robot Learning and Vision for Navigation

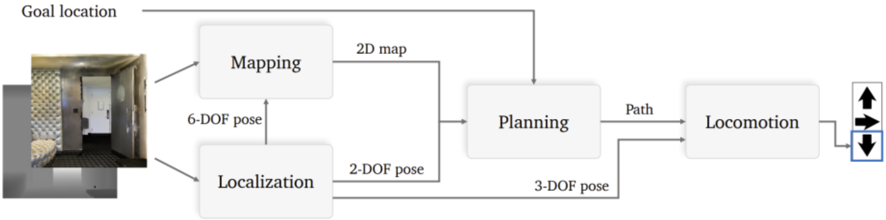


- In robotics research, vision is ***assumed a solved task***.
- Perfect knowledge of the state
- ***Decoupled*** perception from action

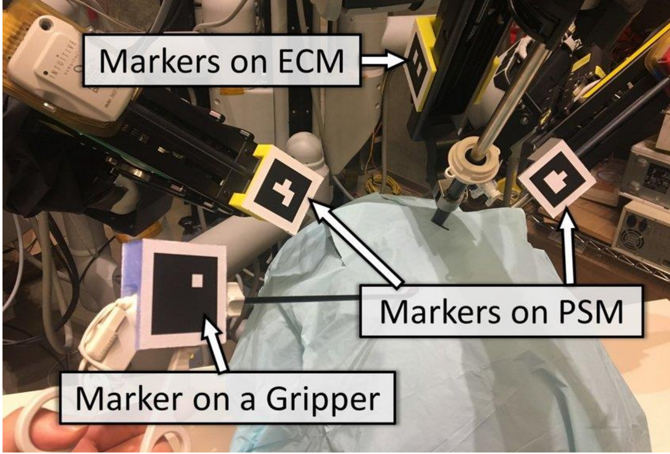
Classic sensorimotor control pipeline

- Perception system constructs a map of the environment
- Planner generates waypoints
- Continuous controller (e.g., proportional-derivative) actuates

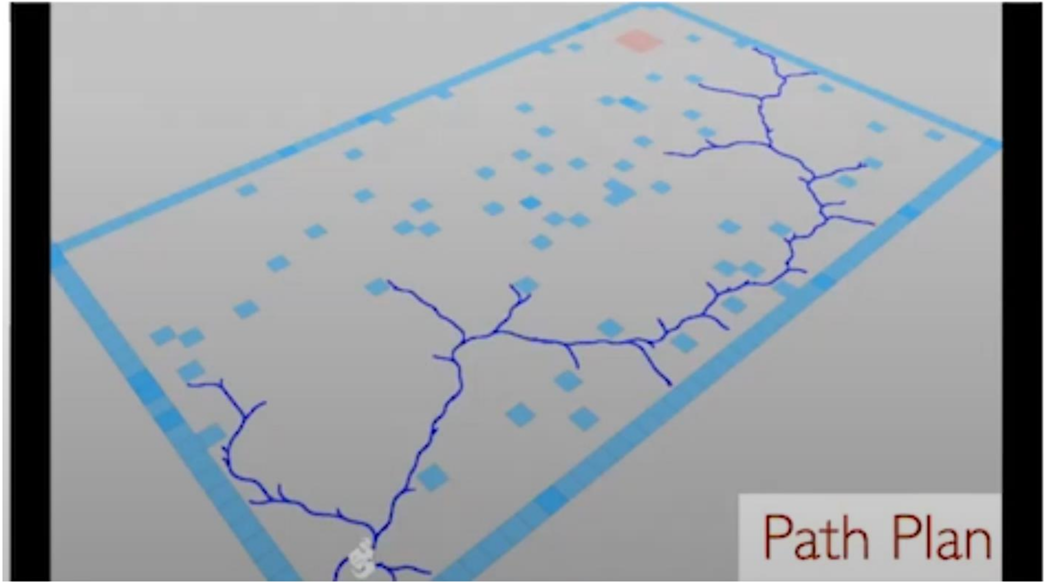
- **What matters is action**
- SLAM (Simultaneous Localization and Mapping) is solving a problem that may be both unnecessarily hard and incomplete
- Biological motivation suggests alternative approaches



Mishkin et al, Benchmarking Classic and Learned Navigation in Complex 3D Environments, 2019


Markers on ECM
Markers on PSM
Marker on a Gripper


Boston Dynamics



Rapidly exploring random trees, Lavalle, Kuffner

The planner will take care of it

- SLAM does not tell us how to explore, navigate, accomplish goals
- But planners assume that the map is accurate and sufficiently complete
- When this assumption breaks, the whole system can fail

What if you need to move in order to see better?

Hints from Natural World

Critique of Pure Vision

Vision, like other sensory functions, has its evolutionary rationale rooted in improved motor control. Although organisms can of course see when motionless or paralyzed, the visual system of the brain has the organization, computational profile, and architecture it has in order to facilitate the organism's thriving at the four Fs: feeding fleeing, fighting, and reproduction. By contrast, a pure visionary would say that the visual system creates a fully elaborated model of the world in the brain, and that the visual system can be studied and modeled without worrying too much about the nonvisual influences on vision.
- Churchland, Ramachandran, and Sejnowski (1994)

https://papers.cnl.salk.edu/PDFs/A%20Critique%20of%20Pure%20Vision%201994-2933.pdf

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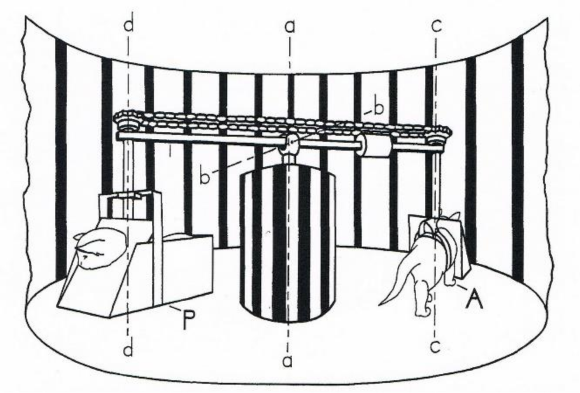
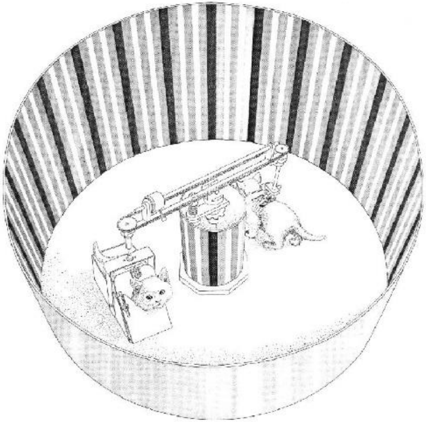
Critique of Pure Action!

https://papers.cnl.salk.edu/PDFs/A%20Critique%20of%20Pure%20Vision%201994-2933.pdf

On the Importance of Interactive Intelligence

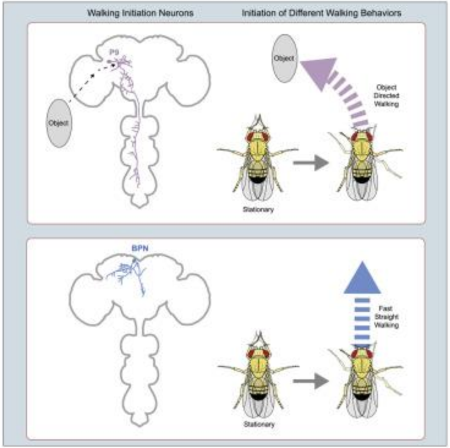




Held and Hein: Movement-produced stimulation in the development of visually guided behavior. Journal of Comparative and Physiological Psychology, 1963.

On the Importance of Interactive Intelligence

the brain switches perception and response to sensory stimuli depending on internal state and needs



Two Brain Pathways Initiate Distinct Forward Walking Programs in *Drosophila, Neuron, 2020*
Sten et al., An arousal-gated visual circuit controls pursuit during *Drosophila* courtship, bioRxiv, 2020

On the Importance of Interactive Intelligence

The ***<u>Gaze Heuristic</u>*** – how to catch a flying ball?

CALCULATE TRAJECTORY:

$$z(x) = x\left(\tan\alpha_0 + \frac{mg}{\beta v_0 \cos\alpha_0}\right) + \frac{m^2 g}{\beta^2}\ln\left(1 - \frac{\beta}{m}\frac{x}{v_0 \cos\alpha_0}\right)$$

GAZE HEURISTIC:

1. Fix your gaze on the ball,
2. start running, and
3. adjust your running speed so that the angle of gaze remains constant.

Gigerenzer, "Homo Heuristicus: Why Biased Minds Make Better Inferences“, 2009


ViralHog

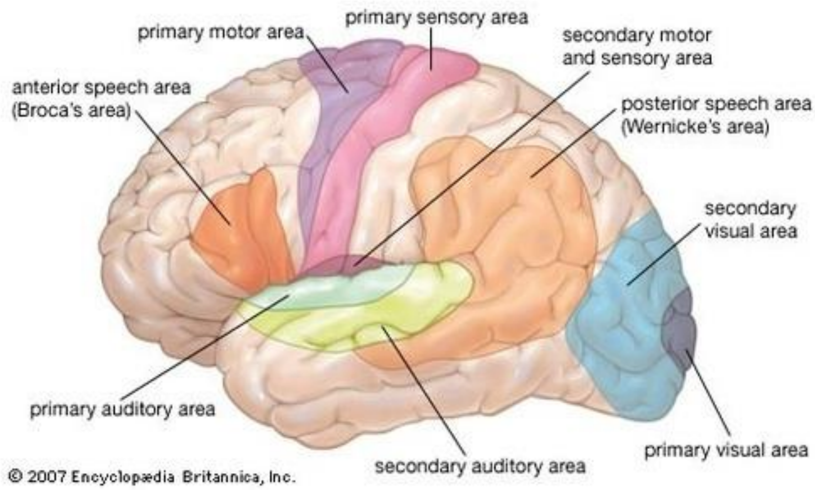
expression of 24 olfactory receptor genes in the AWA olfactory neuron is influenced by a wide array of states and 25 stimuli, including feeding state, physiological stress, and recent sensory cues

Diverse states and stimuli tune olfactory receptor expression levels to modulate food-seeking behavior, bioRxiv, 2022

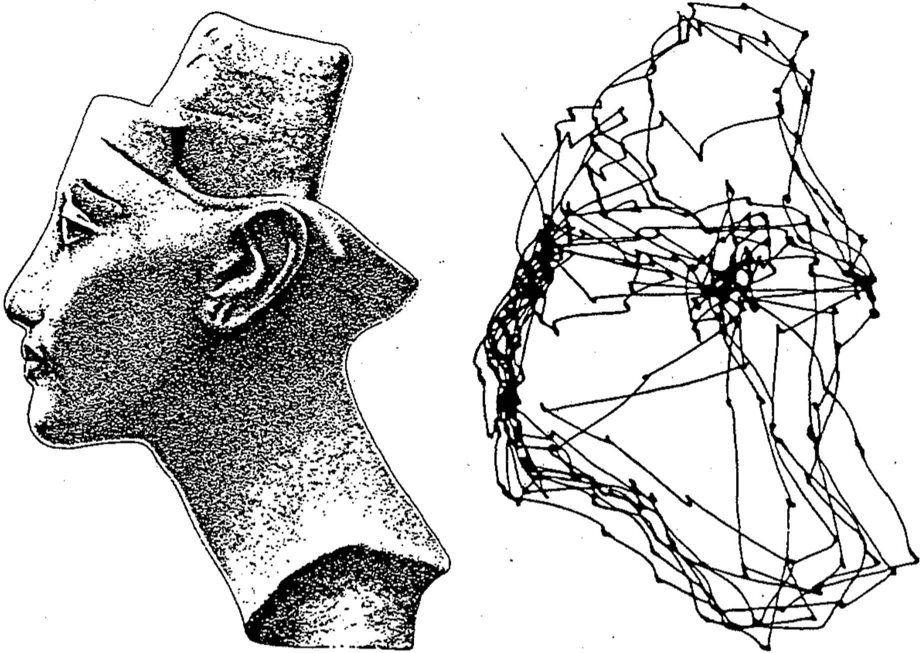
https://www.biorxiv.org/content/10.1101/2022.04.27.489714v1.full.pdf

Acoustic motion of a spider orb-web

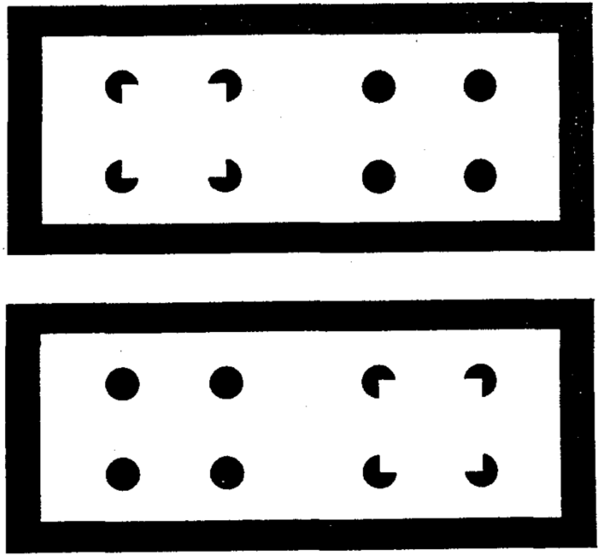
Outsourced hearing in an orb-weaving spider that uses its web as an auditory sensor, PNAS, 2022



Keller GB, et al (2012). Sensorimotor Mismatch Signals in Primary Visual Cortex of the Behaving Mouse. *Neuron*.




TikTok
@ freighttrainofficial



Tentative Agenda

Introduction	Markov Decision Process	Model-based RL
Deep Imitation Learning	Q-Learning and SARSA	Sim2Real
Deep Imitation Learning	Double Q-Learning and Deep RL for Robotics	Bio-Inspired and Evolutionary Techniques
Affordances and Direct Perception	TRPO, DDPG, PPO	Incorporating Language
Dynamics and Localization	LfD/Inverse Reinforcement Learning	Partial Observability
Semantic Scene Understanding	Human-in-the-Loop Learning	Human-Robot Interaction
Object Detection and Tracking		Ethics and Social Implications

Materials

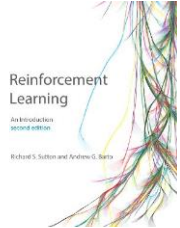
Lecture slides, class-room writing (blackboard)

Exercise slides & assignments

Books:

Sutton, Barto:

Reinforcement Learning: An Introduction



Paper readings that will be announced in class.

Grading

Grading

Class Quizes (10%): Quizzes will be given at the end of each main class theme and will draw on concepts from presented material and papers.

Homework (30%): Homework will require coding in Python and PyTorch. GPU-cluster access will be provided and are highly recommended. Familiarity with Python will be assumed. Prior experience with PyTorch or Tensorflow is not required but is a plus.

Presentations and Participation (20%): Each student will get the opportunity to present. You will be graded based on your level of insight into the material, clarity and depth of presentation, how well you relate the paper to other papers and lecture material, as well as a lead discussion.

Final Project (40%): Each student is required to on a final research project. The project requires a 2-page proposal including the relevant literature survey, a proposal presentation, a milestone review, a 6-10 page-long final report, and a final presentation/demo. Projects are expected to be research level, uncovering new knowledge, and could be done either in simulation or on a real platform.

Team

Kathakoli Sengupta

Animikh Aich

Office hours: Wednesdays after class, 6:15-7:15?

Homework 0

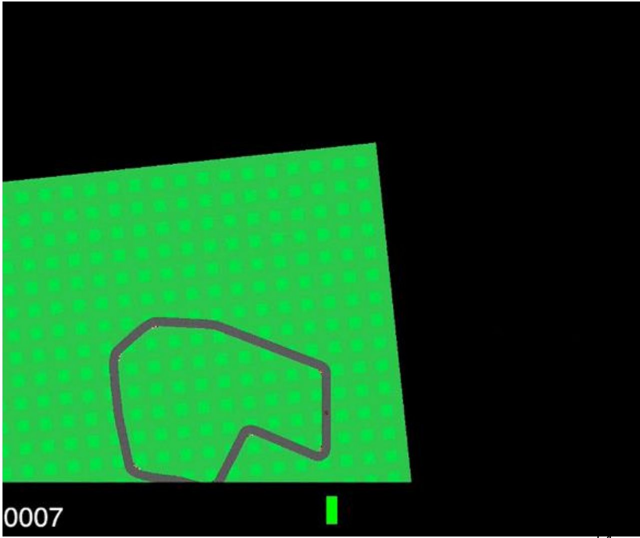
- Posted on Blackboard, setup environment. Due 11:59PM on Monday 9/11.

SCC Cluster

- All students should have access.
- Some haven’t used before.
- Not required for completing the exercises, but may be useful, specifically for class competition.

HW 0 details (Due Monday at 11:59 PM)

OpenAI Gym: Car Racing Environment



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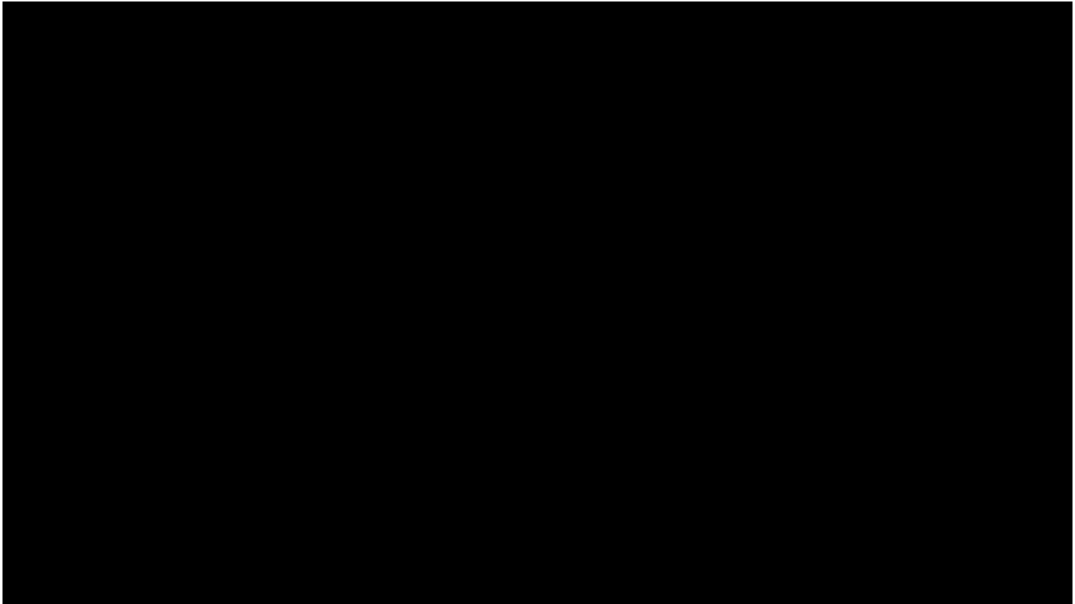


PyTorch

- ►What is PyTorch?

  A Python-based scientific computing package for Deep Learning.
- ►Why PyTorch?

  Beginner friendly, well documented, good for fast development.
- ►How to install?

  https://pytorch.org/get-started/locally/
- ►Can use PyTorch 1.3

Basic Computations

Tensor

► Construct a Tensor

```python
x = torch.zeros(8, 3)
print(x)
```

```
tensor([[0., 0., 0.],
        [0., 0., 0.],
        [0., 0., 0.],
        [0., 0., 0.],
        [0., 0., 0.],
        [0., 0., 0.],
        [0., 0., 0.],
        [0. ,0.,0.]])
```

```python
x = torch.rand(8, 3)
print(x)
```

```
tensor([[0.0984, 0.3671, 0.2543],
        [0.5016, 0.8017, 0.0918],
        [0.5081, 0.6020, 0.0867],
        [0.5313, 0.4571, 0.1624],
        [0.4231, 0.3993, 0.2713],
        [0.8978, 0.6039, 0.8519],
        [0.4829, 0.6648, 0.8295],
        [0.9060, 0.2132, 0.4110]])
```

Basic Computations

Operations

- Multiple syntaxes, e.g. Addition

```
y = torch.rand(8, 3)
print( x+y)
```

```
print(torch.add(x, y))
```

```
#providing an output tensor as argument
result = torch.empty(8, 3) torch.add
(x, y, out=result) print(result)
```

```
#adds x to y y.
add_(x) print(y)
```

- Other operations including transposing, indexing, slicing, linear algebra etc. at
  https://pytorch.org/docs/stable/torch.html
  http://rcs.bu.edu/examples/ML/pytorch/

Open AI Gym Work flow

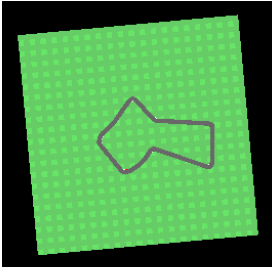
```
import gym
env = gym.make('CarRacing-v0')
init_state = env.reset()

for i in range(1000):
    # used to display the environment, useful for visualization/debugging
    env.render()

    # take a random action
    (next_state, reward, is_terminal, debug_info) = env.step(env.action_space.sample())
```

Car Racing

- Randomly generated tracks

Car Racing

- action space: three continous values, including steer, gas, brake

```
self.action_space = spaces.Box( low=np.array([-1,0,0]),
                                high=np.array([+1,+1,+1]), dtype=
                                np.float32)
```

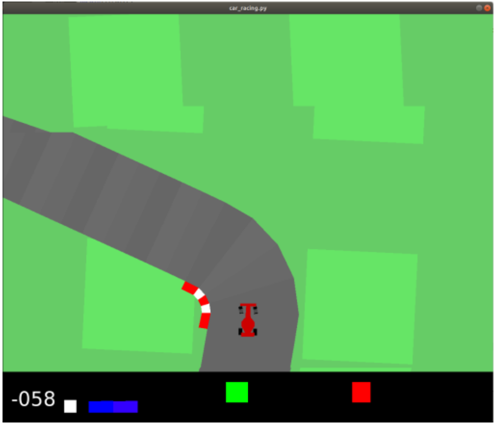
- observation space: color image

```
self.observation_space = spaces.Box(low=0, high=255,
                                    shape=(STATE_H, STATE_W, 3),
                                    dtype=np.uint8)
```

- reward: $R = N_{visited\ tile} * \frac{1000}{N_{all\_tile}} - N * 0.1$

Example: For 732 steps, R = 1000 – 0.1*732 = 926.8 points

Car Racing



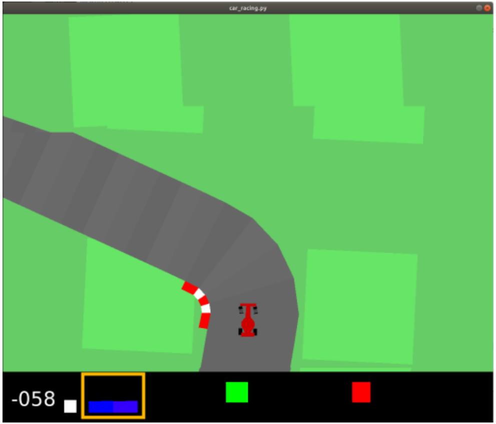
Car Racing

- ▶ Reward

Car Racing

- Reward
- Car speed

Car Racing



- Reward
- Car speed
- Wheel speed

Car Racing

- Reward
- Car speed
- Wheel speed
- Joint angle

Car Racing

- Reward
- Car speed
- Wheel speed
- Joint angle
- Angular Velocity

Exercise 0

Install OpenAI Gym locally

- Python 3.5+
- Download sdc gym.zip from blackboard
- Install the box2d package

```
pip3 install -e '.[box2d]'
```