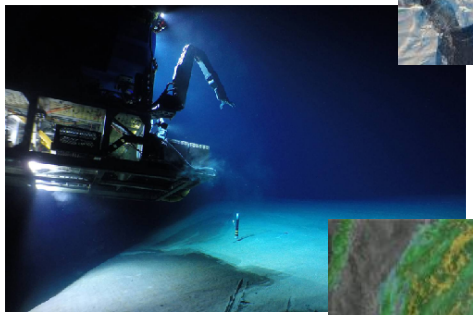
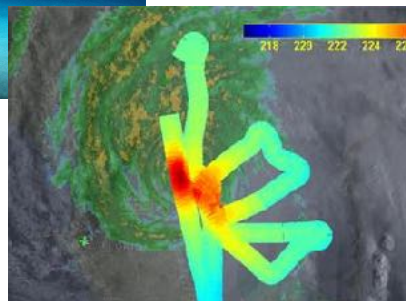
Increasing Autonomy in Scientific Sampling Robots

Johanna Hansen
PhD Student in the Mobile Robotics Lab
Advised by Greg Dudek





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Centre for Intelligent Machines

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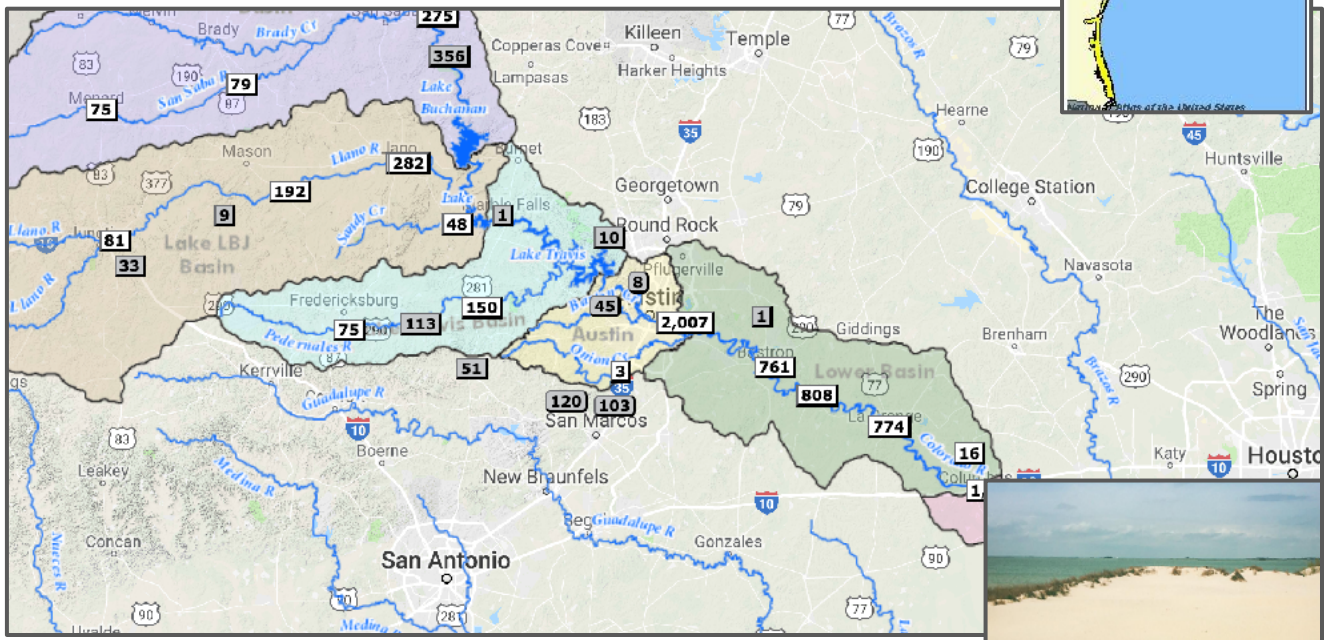
image source: JPL, WHOI

B.S. Environmental Geography & Electrical Engineering



https://hydromet.lcra.org/

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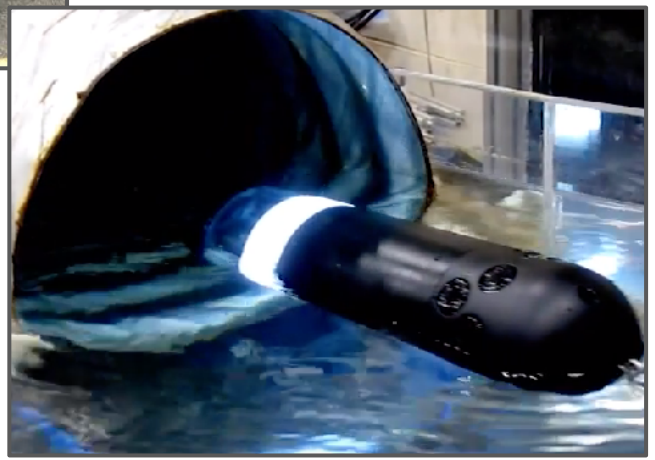
B.S. Environmental Geography & Electrical Engineering

Low-Cost Environmental Sensors



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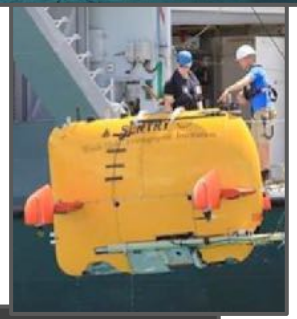
http://www2.swri.edu/9what/releases/2010/cavemap.htm

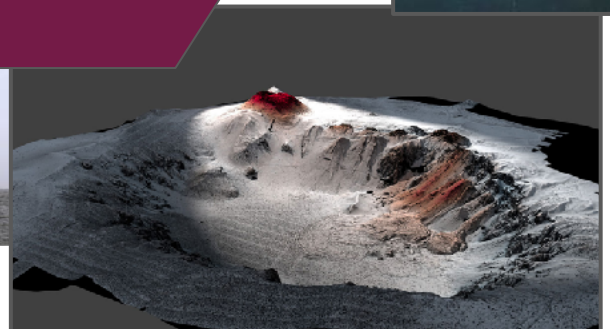
Hansen et al, “The Ultrasonic Culvert Inspection System”, 2014

B.S. Environmental Geography & Electrical Engineering

Low-Cost Environmental Sensors

Deep-Sea Autonomous Vehicles for Science





https://www.whoi.edu/news-release/a-close-up-look-at-a-rare-underwater-eruption

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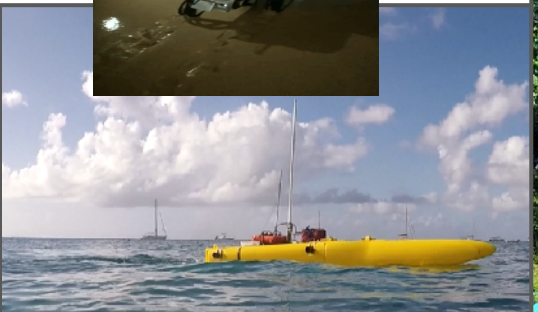
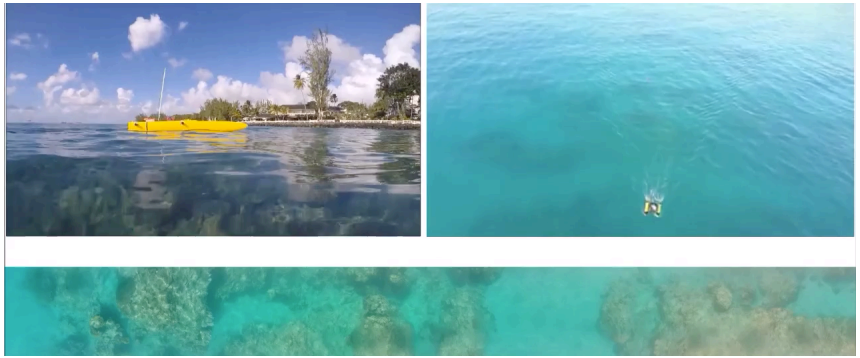
Mobile Robotics Lab



Overview

- Introduction
- How to train your robot
- Low-cost persistent monitoring in flow fields
- Round Table: robots in your research
- Time permitted: Ideas to steal from computer vision researchers



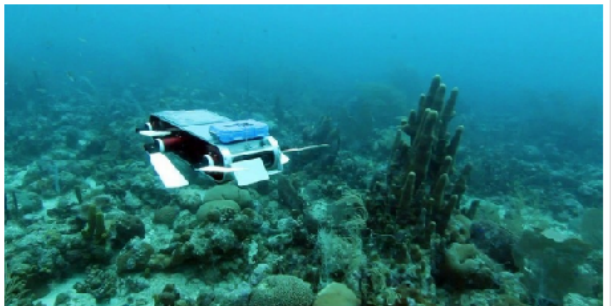


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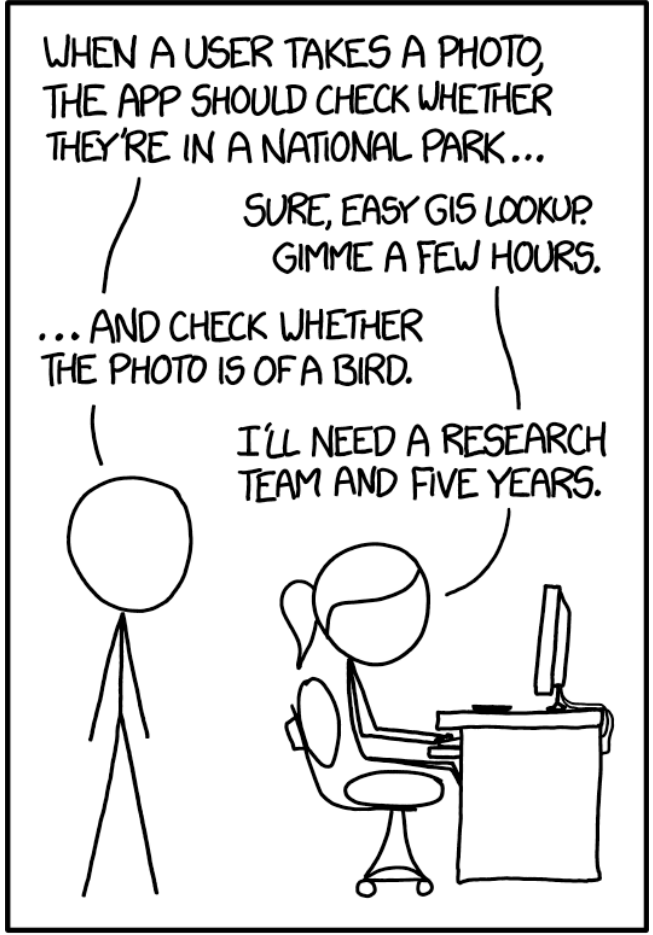
Photo Credit - Sandeep Manjanna, Florian Shkurti



https://xkcd.com/1425/

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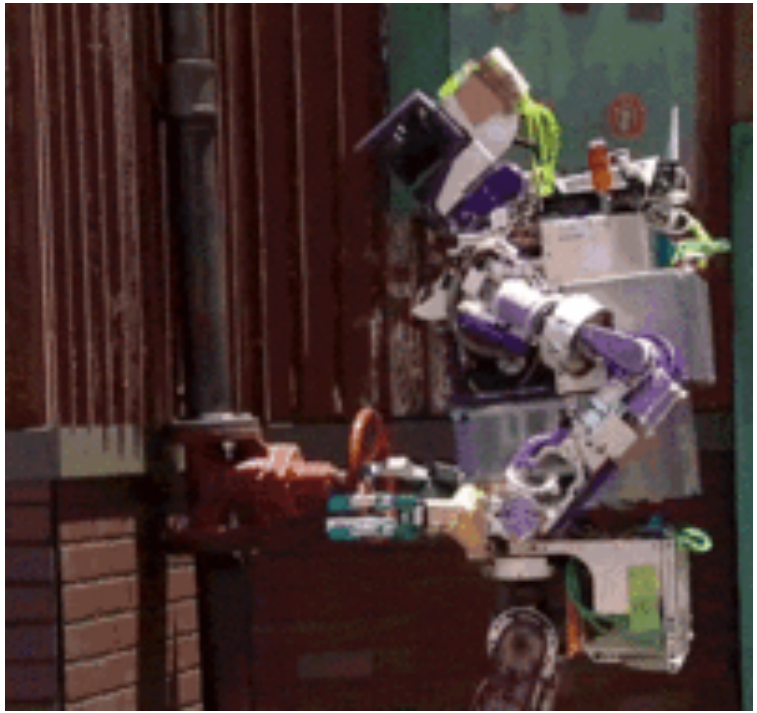

https://spectrum.ieee.org/automaton/robotics/humanoids/darpa-robotics-challenge-robots-falling

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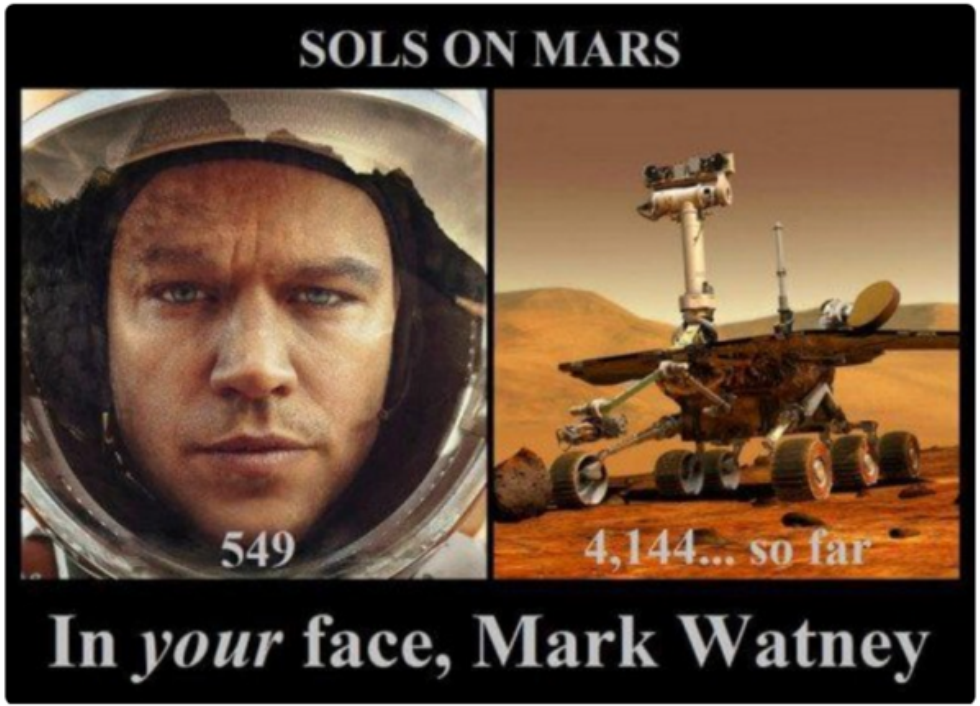
Andy Weir ✓
@andyweirauthor

Following

I love it!



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We can create robots which imitate experts!
(*you* are the expert)

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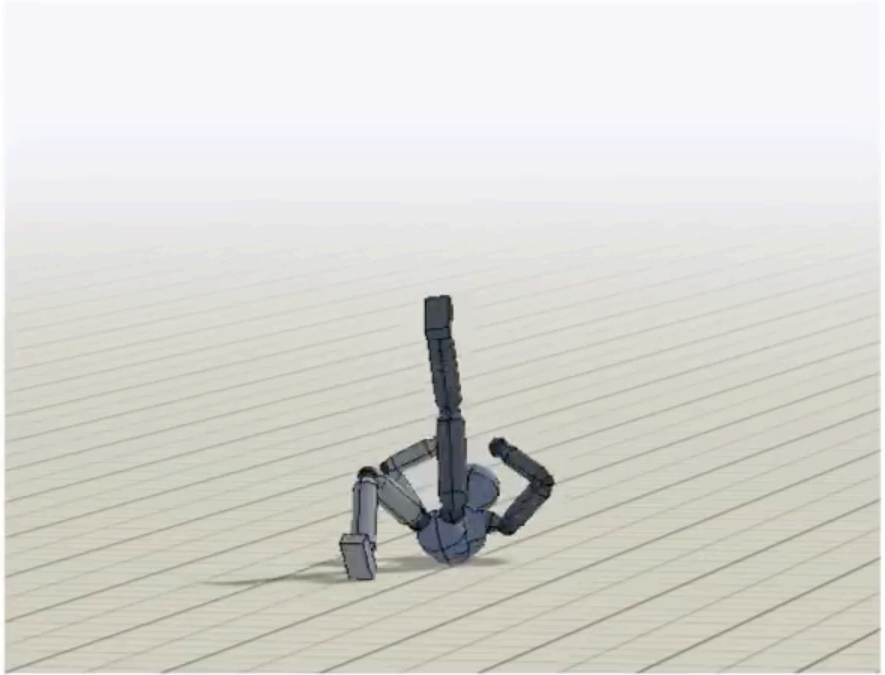
Results

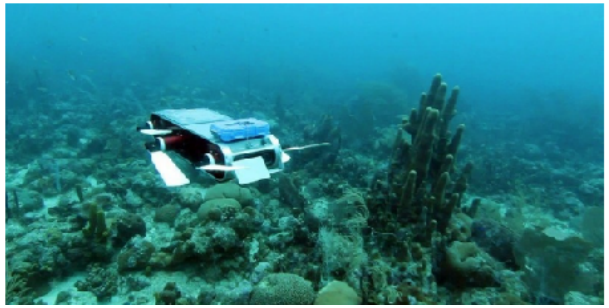
Video: Kip-Up

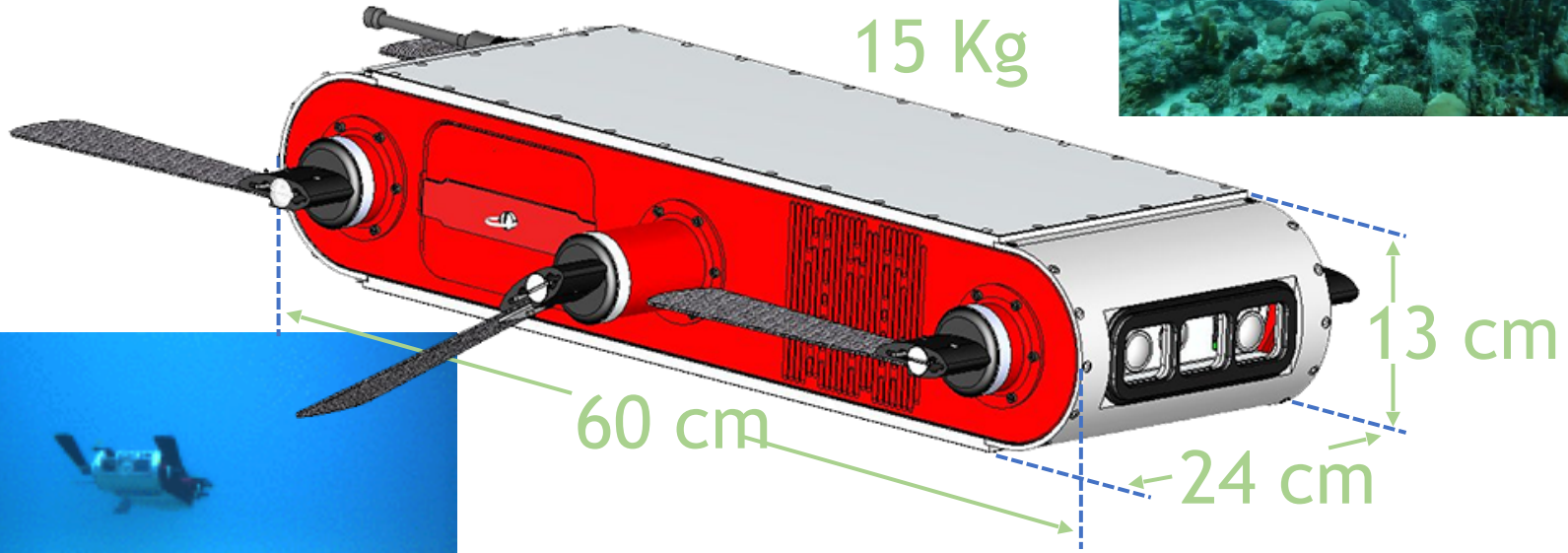


Policy

Peng et al, SFV: Reinforcement Learning of Physical Skills from Videos, 2018

Introducing the Aqua Robot





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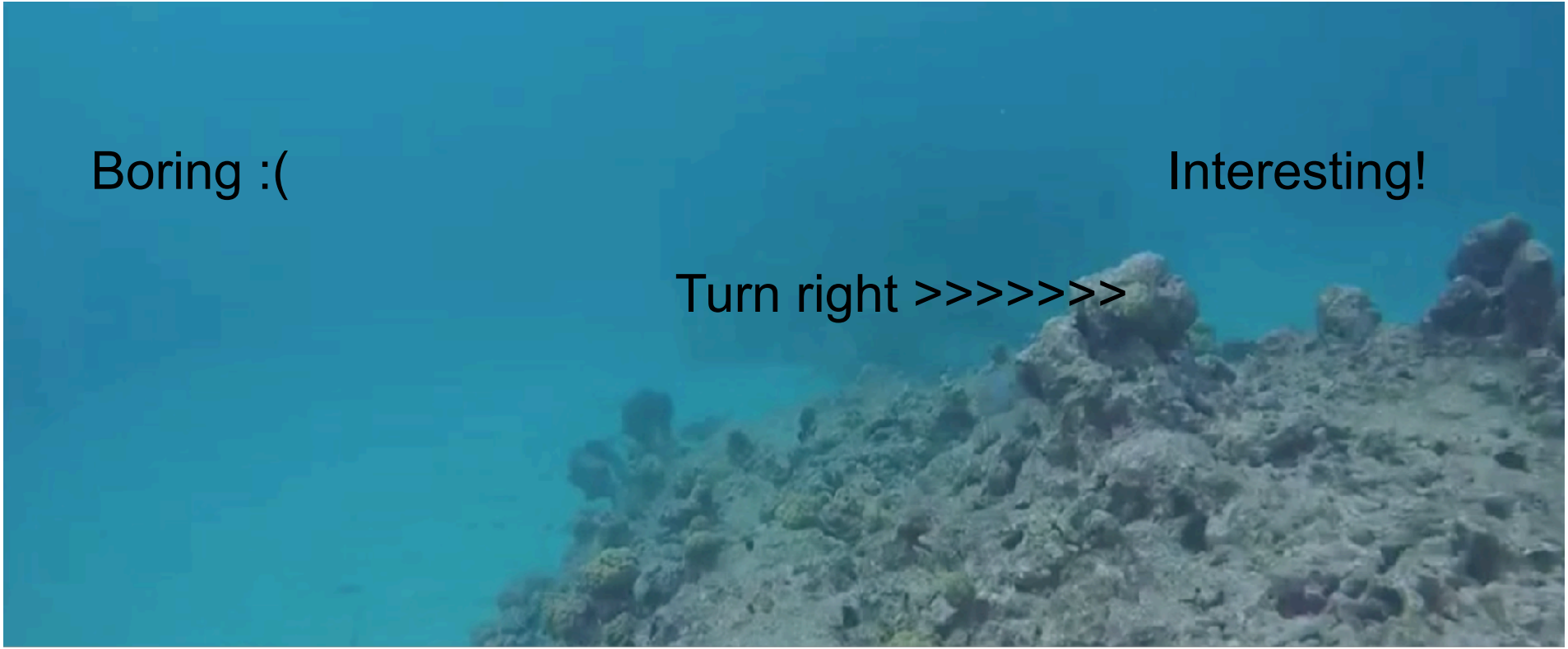
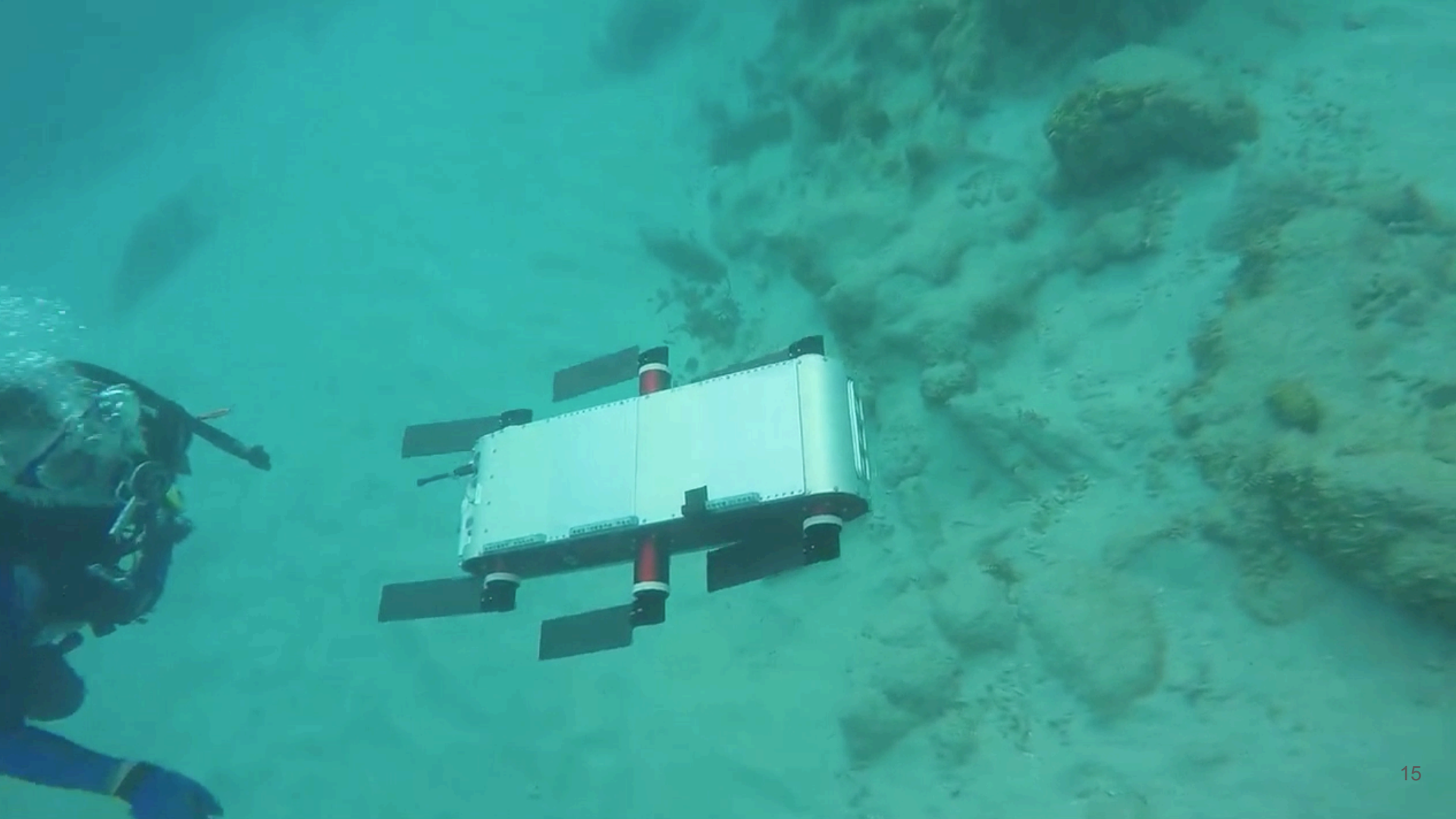
Teaching a Robot to Navigate a Reef



Manderson et al, “Vision-based Autonomous Underwater Swimming in Dense Coral for Combined Collision Avoidance and Target Selection”, 2018



What if we don’t have an expert trace, but do know good/bad behaviors?

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Rewarding Robots

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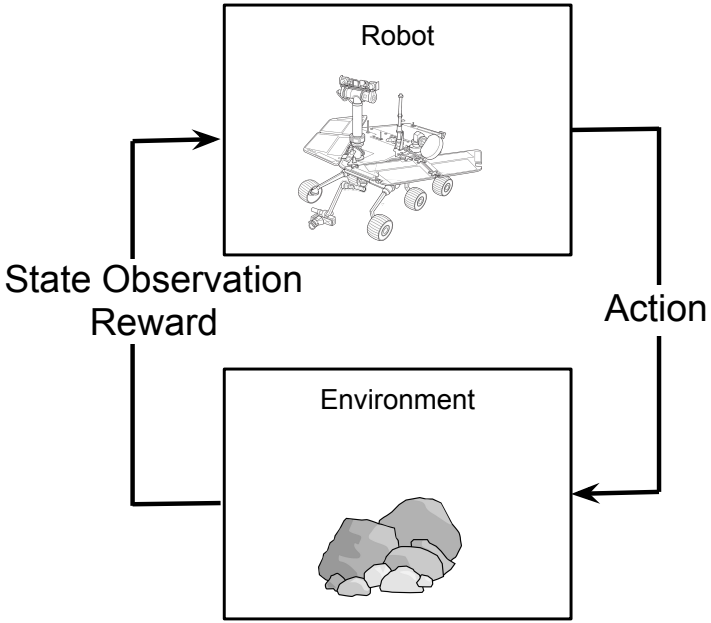
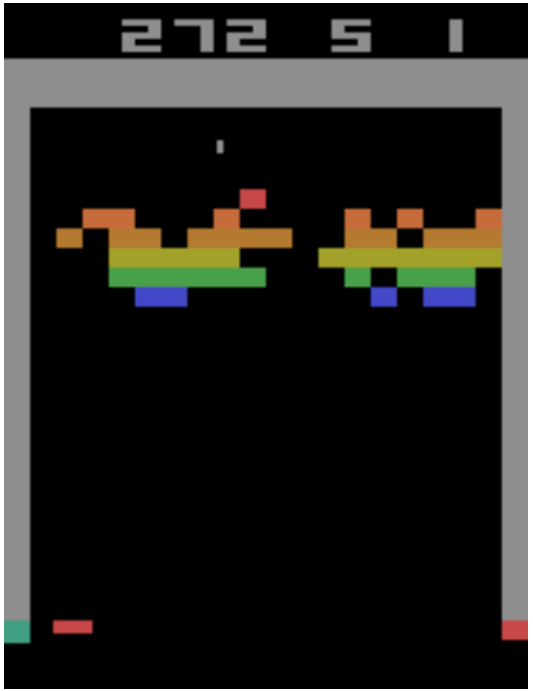
https://giphy.com/gifs/6hbRKWsfqvbkQ





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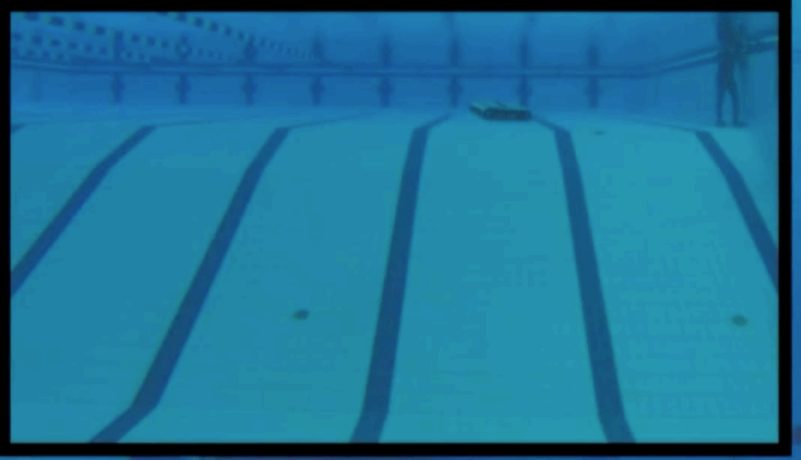

Learning Swimming Gaits From Experience

- The robot builds a model of the dynamics
- As the model gets better, the robot finds a successful swimming controller for the real world

Learning iteration #2

McGill

(2x)

Higuera et al, “Synthesizing Neural Network Controllers with Probabilistic Model-Based Reinforcement Learning”

Teaching robots to sample efficiently through reward specification

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Can we make it easy for scientists to specify what features they want in a robot sample?

Sandeep Manjanna
PhD Candidate in Computer Science - McGill University
https://www.cim.mcgill.ca/~msandeep/
Adaptive sampling algorithms for deploying environment-observing robots

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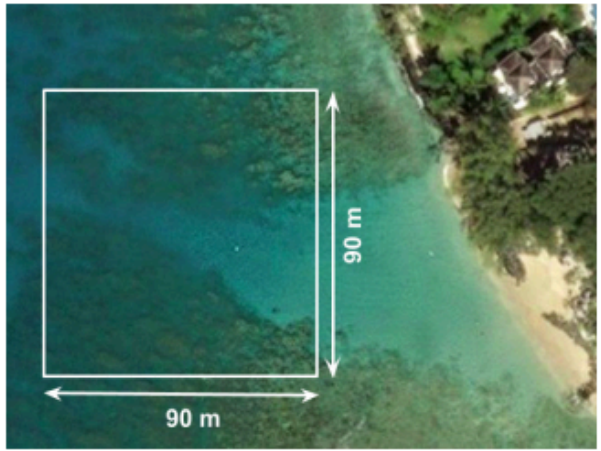
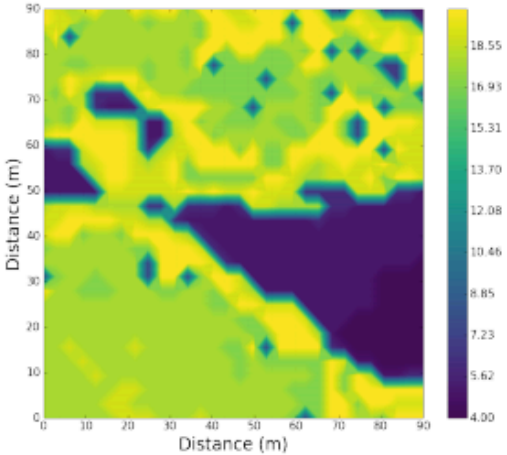
In-Situ Sampling with Autonomous Boats



(a)



(b)

(c)

Manjanna et al, “Policy Search on Aggregated State Space for Active Sampling”, 2018

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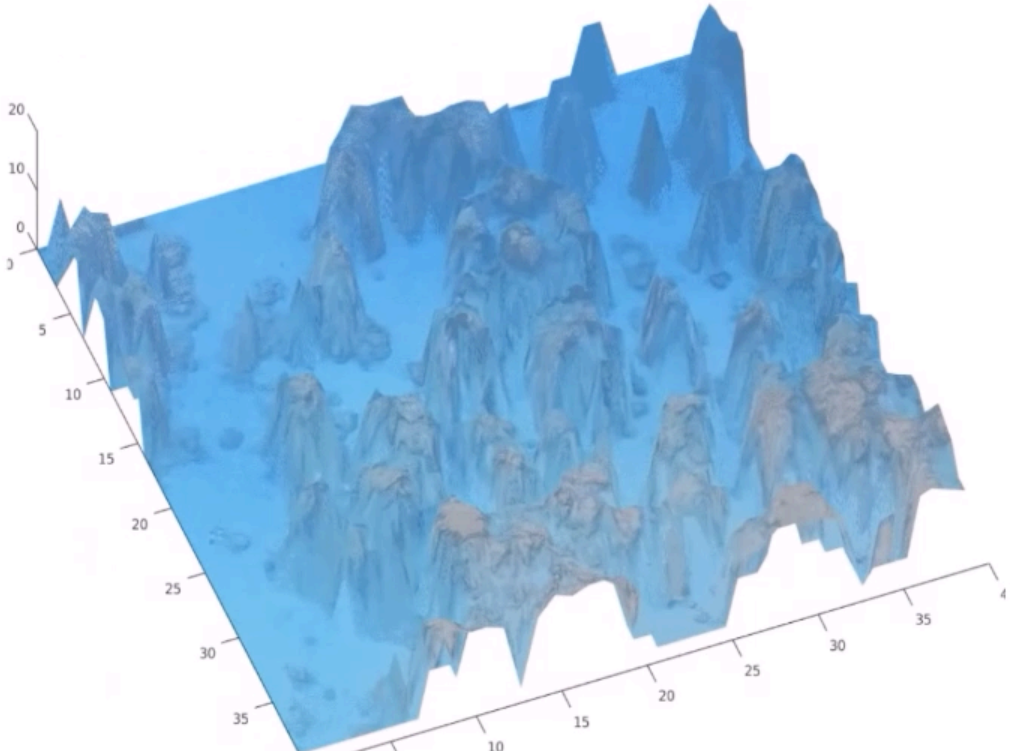
Testing of policy search based sampling algorithm

Test scenario



Manjanna et al, “Policy Search on Aggregated State Space for Active Sampling”, 2018

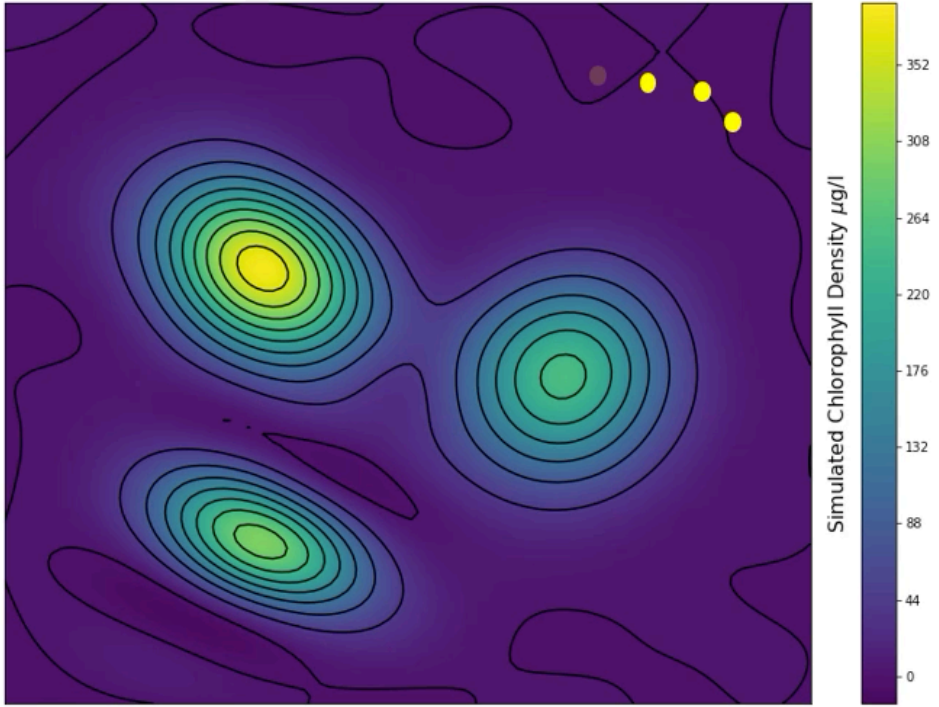
Heterogeneous Multirobot System for Exploration and Strategic Water Sampling

Sandeep Manjanna, Alberto Quattrini Li, Ryan N. Smith, Ioannis Rekleitis and Gregory Dudek

http://www.cim.mcgill.ca/~msandeep

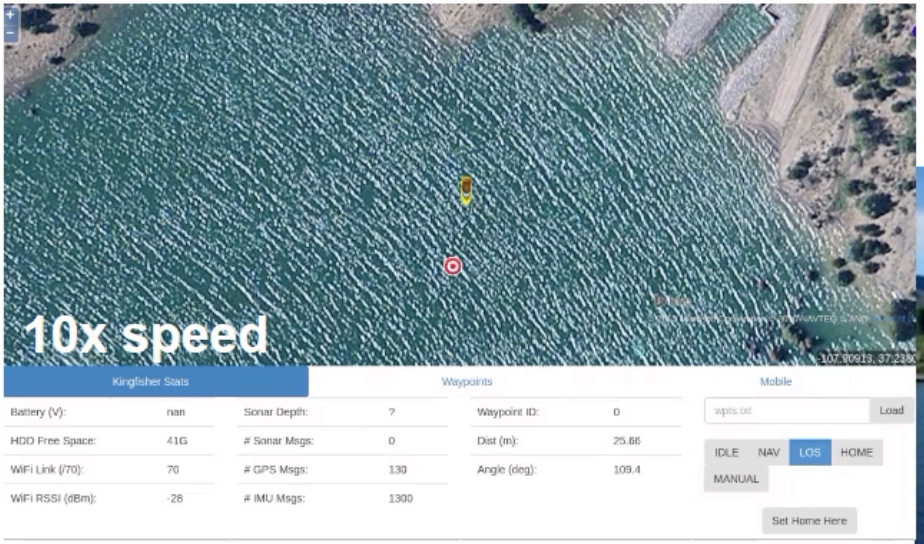
Sampler chooses the candidate for sampling water

Candidate locations for sampling are suggested by the Explorer and the Sampler keeps a list of all the candidate locations.



Manjanna et al, “Heterogeneous Multirobot System for Exploration and Strategic Water Sampling", 2018

Sampler goes to the selected location

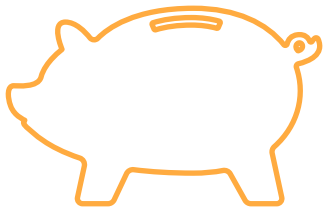


Graphical interface showing the sampler

Sampler and Explorer operating together in the field

Manjanna et al, “Heterogeneous Multirobot System for Exploration and Strategic Water Sampling", 2018

How can we enable robots to collect high spatiotemporal resolution samples from a body of water for a long time?



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Can we enable robots to collect high spatiotemporal resolution samples from a body of water for a long time?

Johanna Hansen
PhD Student in Computer Science - McGill University
Science Twitter: @johanbanan, https://johannah.github.io
Model-based decision making for improved autonomy in scientific surveying robots.

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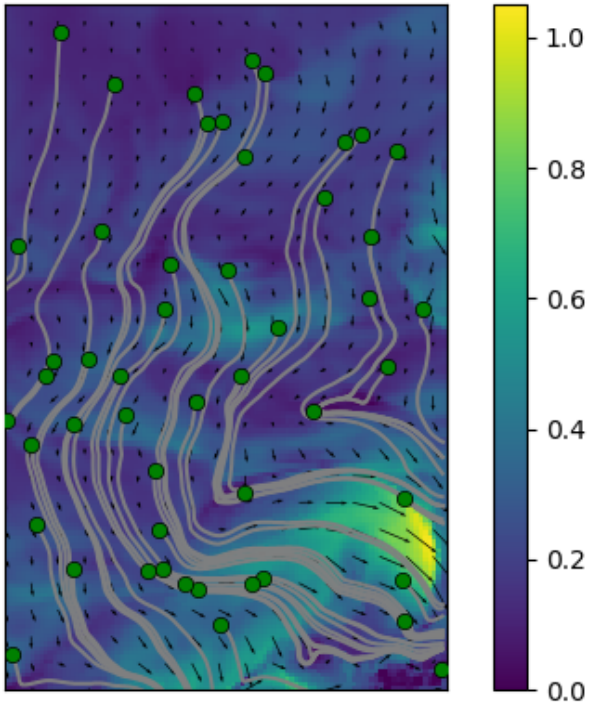
Challenge: Sampling in a Flow Field

- Spatially varying phenomena in dynamic flow field
- Want samples which are:
  - Spatially distinct
  - Collected Simultaneously
  - Spanning “seasons”
- Not all samples are created equal. How can we maximize information gain for time/energy/ financial expense?



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Gold Standard: Sensor Arrays

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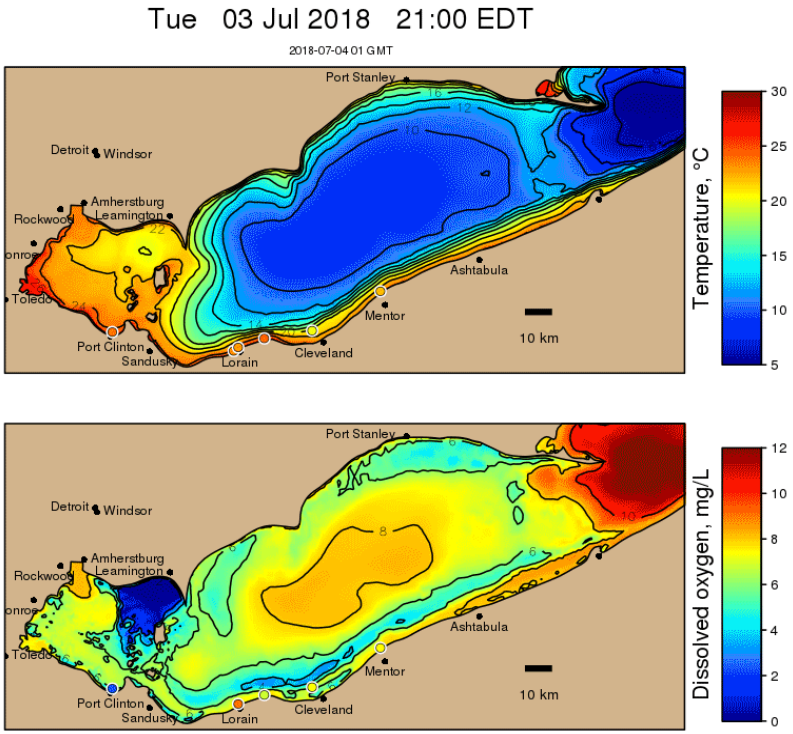
KQED: Battling the Bloom: Lake Erie

Data from Static Sensor Arrays



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https://www.glerl.noaa.gov/data/

Can we replicate this less expensively?

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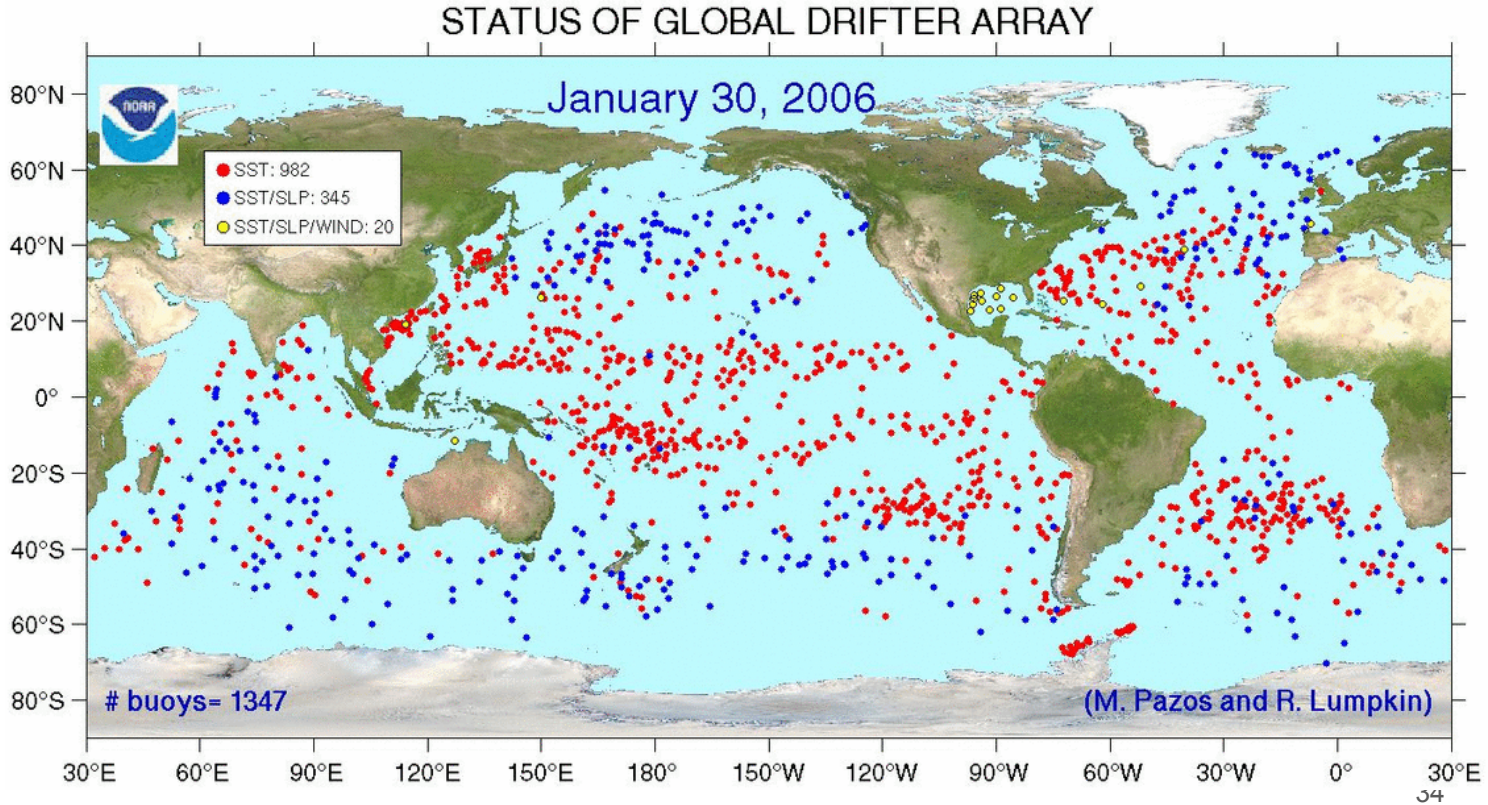
KQED: Battling the Bloom: Lake Erie

Team of Autonomous Vehicles

johanna.hansen@mail.mcgill.ca

KQED: Battling the Bloom: Lake Erie

Leverage flow field to transport sensors!



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https://www.aoml.noaa.gov/phod/gdp/index.php

Heterogeneous Team of Autonomous Samplers

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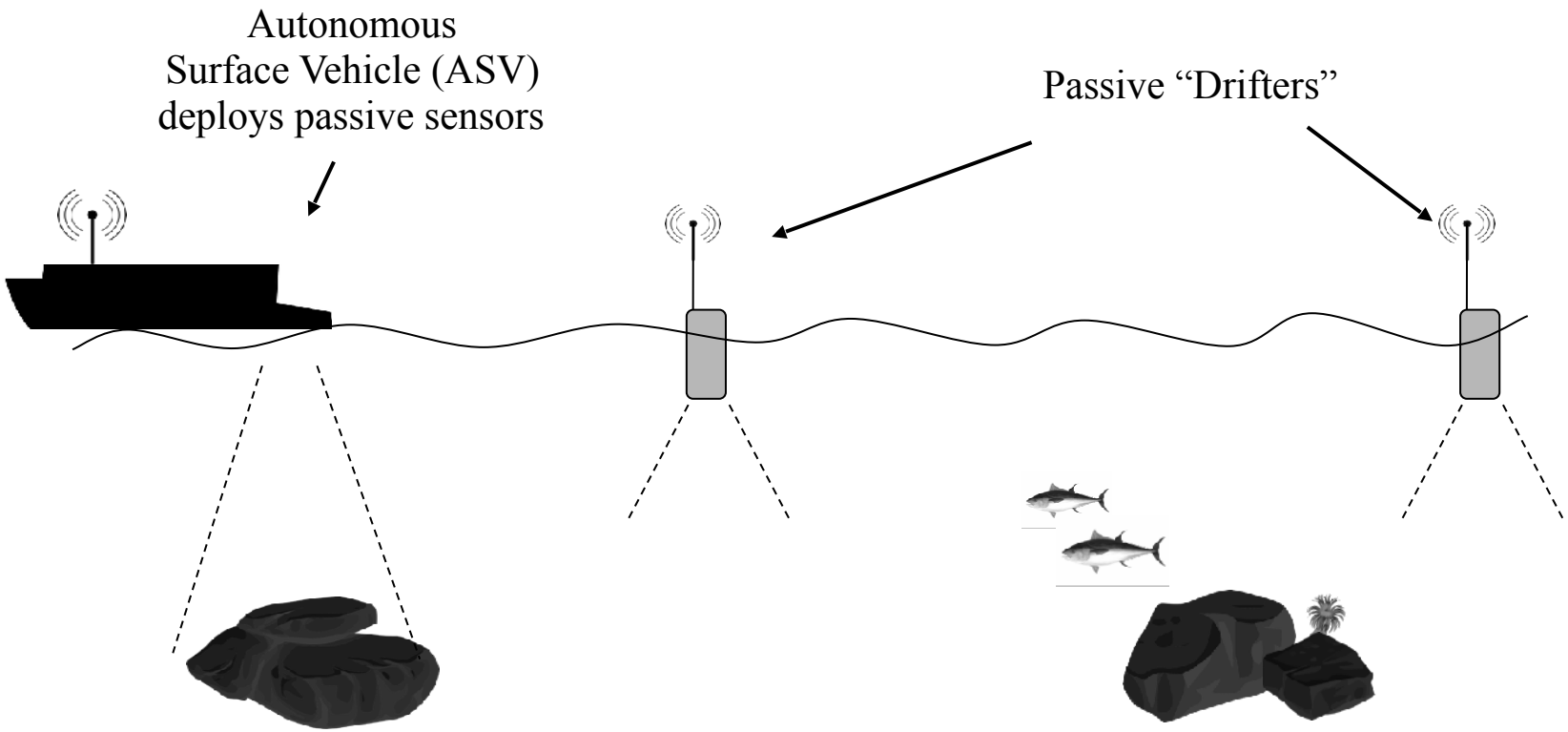
KQED: Battling the Bloom: Lake Erie

Coastal Autonomous Drifter Deployment



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Autonomous Boat + Drifters = A Great Team

- Relatively expensive
- Limited deployment time
- Controllable

- Inexpensive
- Long-lasting
- “Free” transport
- Difficult to control

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What makes this problem interesting?

- Drifters are only controllable at deployment
- Robot movement is expensive
- Retrieving drifters takes time and is unforgiving

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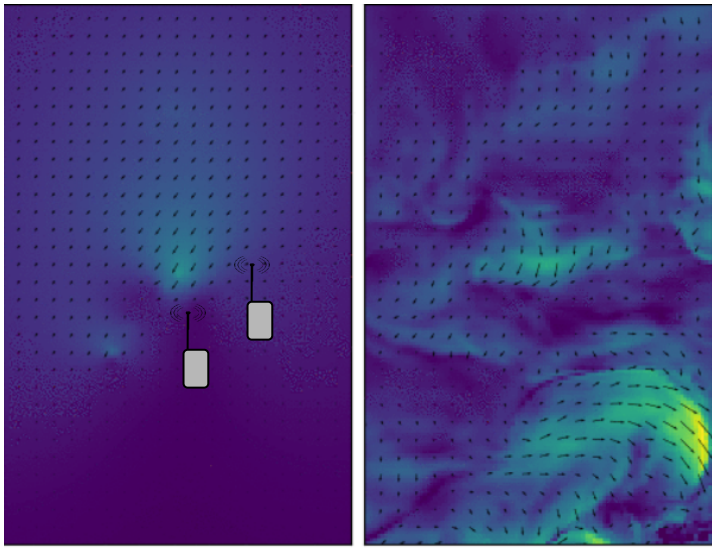
Where should we release drifters?

- Explore/exploit dilemma
- Unknown flow field initially
- Flow field needed for drifter transport!
- Unknown and changing distribution of “phenomena of interest”



Estimate Flow Field True Flow Field

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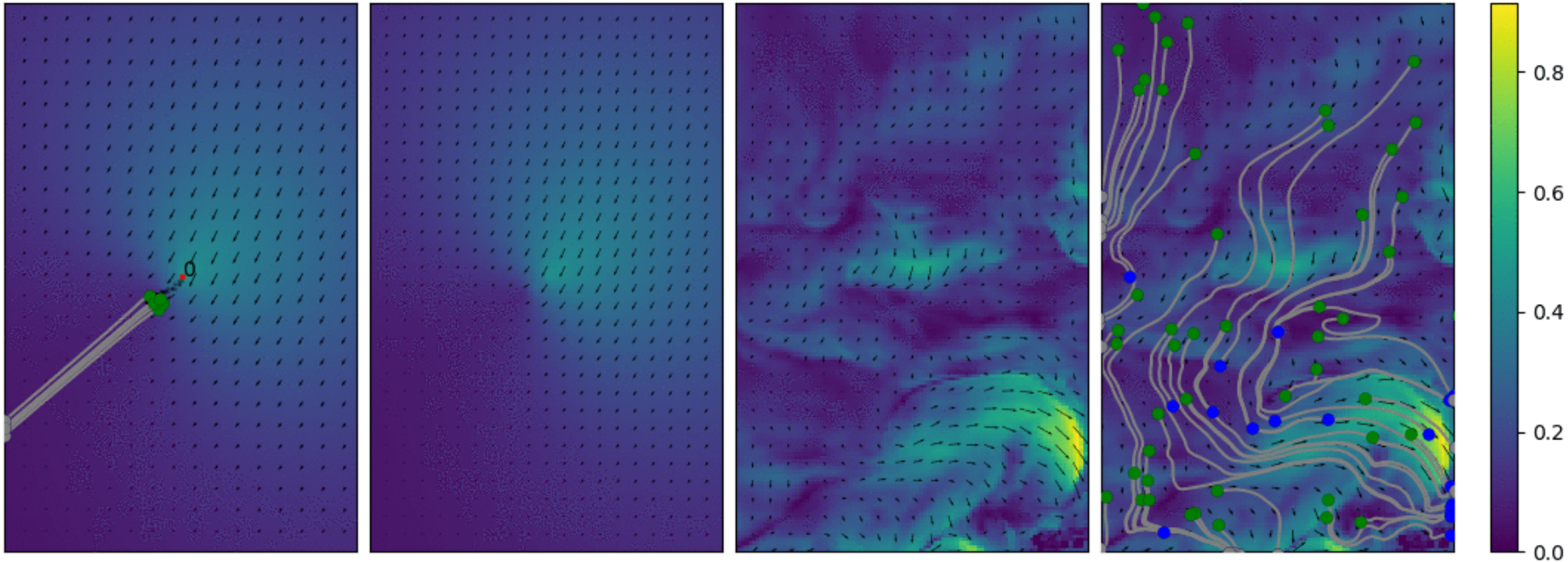
Optimize drifter deployment for coverage



Deployment | Estimate Flow Field | True Flow Field | Flow Field Visualization

Hansen et al., "Coverage optimization with non-actuated, floating mobile sensors using iterative trajectory planning in marine flow fields", 2018

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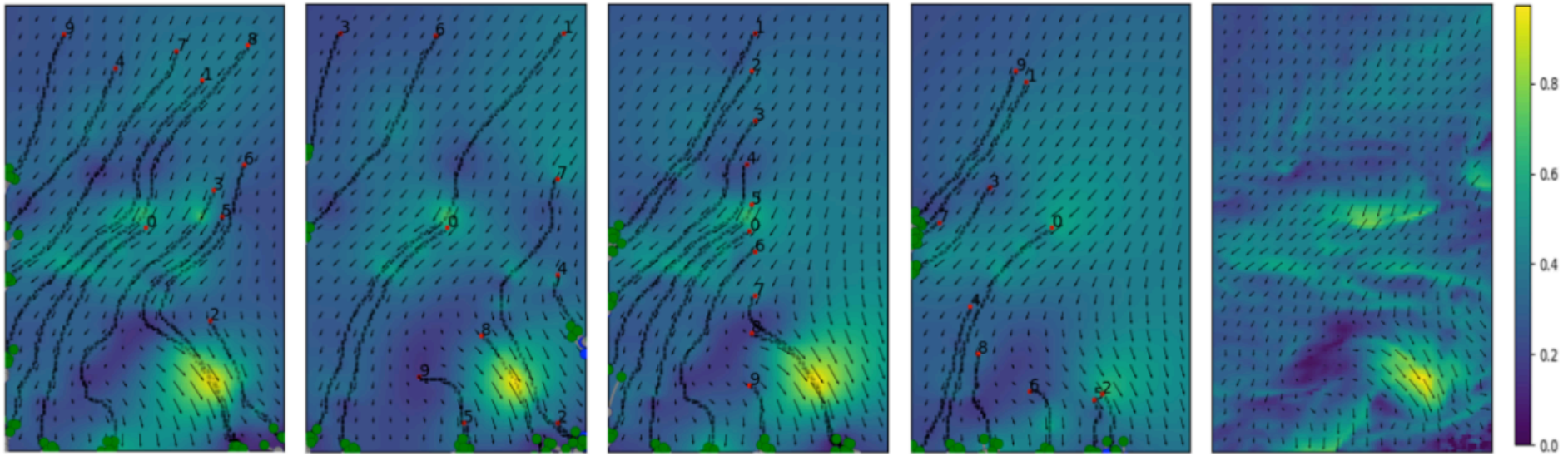
Optimize drifter deployment for coverage



(a) ours (b) variance (c) distributed long (d) random (e) ground truth (f)

Hansen et al., "Coverage optimization with non-actuated, floating mobile sensors using iterative trajectory planning in marine flow fields", 2018

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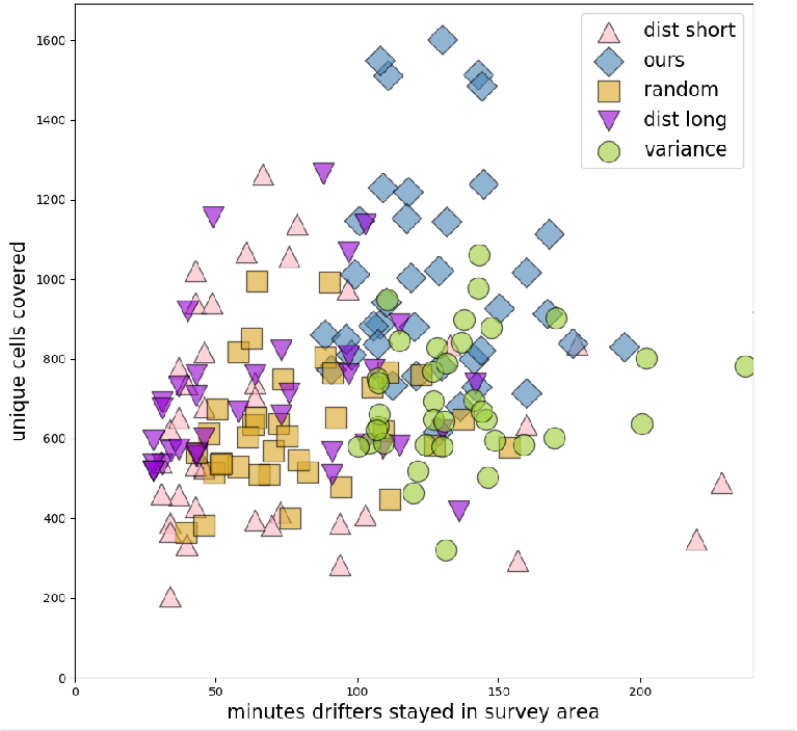
Coverage Results



Hansen et al., "Coverage optimization with non-actuated, floating mobile sensors using iterative trajectory planning in marine flow fields", 2018

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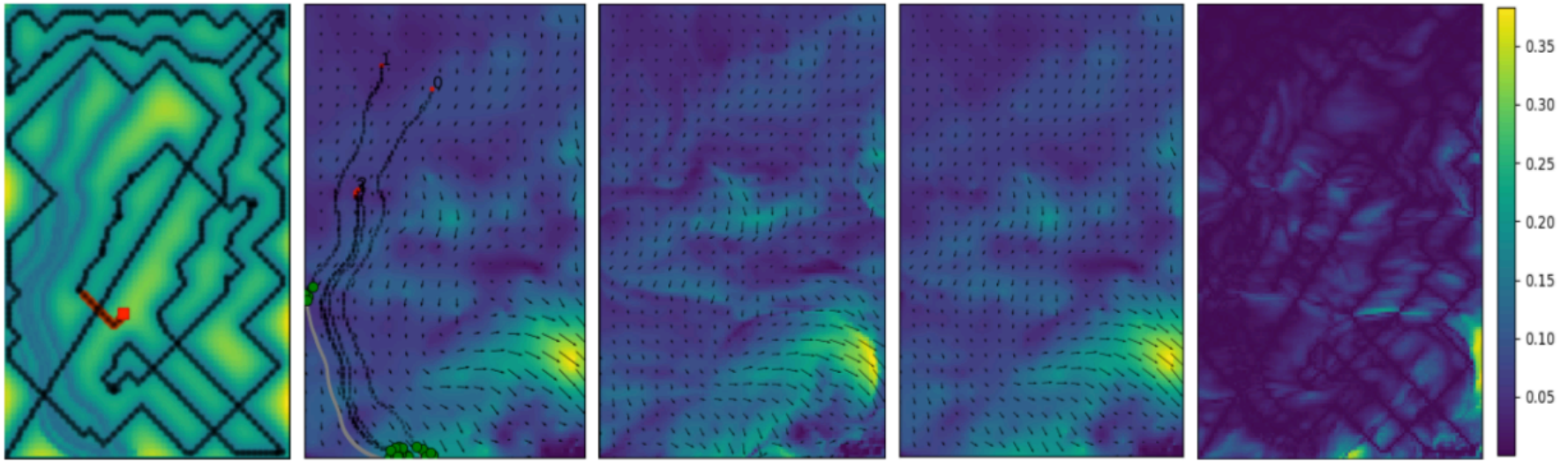
Cooperative Sampling with Boat and Drifters



(a) ASV Path (b) Drifter Path (c) True Flowfield (d) Estimate (e) Final RMSE (f)

Hansen et al, "Autonomous Marine Sampling Enhanced by Strategically Deployed Drifters in Marine Flow Fields", 2018

Future Work

- Fast fluid simulations
- Learned prior such as satellite image, bathymetry
- Drifter redeployment for persistent monitoring
- Active drifters
- Collaborations!

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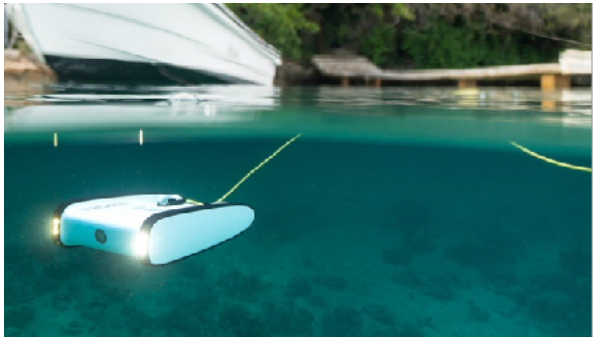
Opportunities

- Robots that learn to sample like scientists
- Domain experts define reward functions, robots learn automatically
- Deploy intelligent behaviors to cheap robots
- Physical Simulations
- Incorporate techniques from computer vision to scientific data



www.openrov.com
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www.bluerobotics.com
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Model-based decision making for improved autonomy in scientific surveying robots.

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Adaptive sampling algorithms for deploying environment-observing robots

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Mobile Robotics, Machine Learning, Intelligent systems, Machine Vision, Web application services, Collaborative Filtering, Image processing

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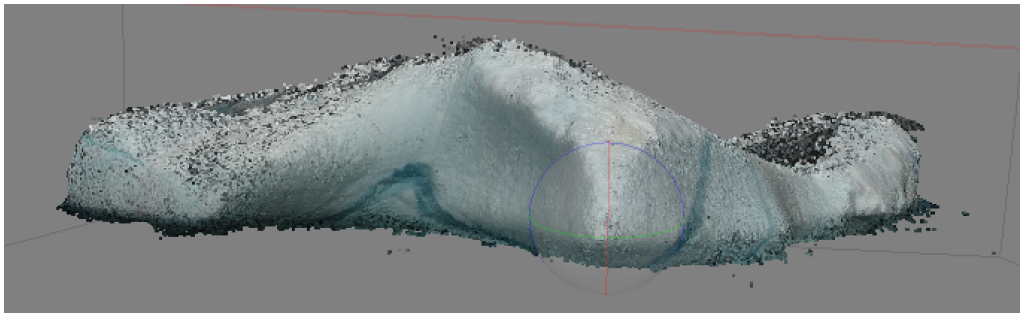
Things we are excited about

- Anything Ice
- Persistent Monitoring
- Low-Cost Sensors (what can we do with cameras/ thermometers?)
- Integrating Experts
- Cool Data



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Round Table Discussion

https://www.cim.mcgill.ca/~mrl/pubs/jhansen/GRIL.pdf

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Photo Credit - Sandeep Manjanna

Computer Vision is *Really* Good

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Figure 1: Class-conditional samples generated by our model.

Brock et al, LARGE SCALE GAN TRAINING FOR HIGH FIDELITY NATURAL IMAGE SYNTHESIS, 2018

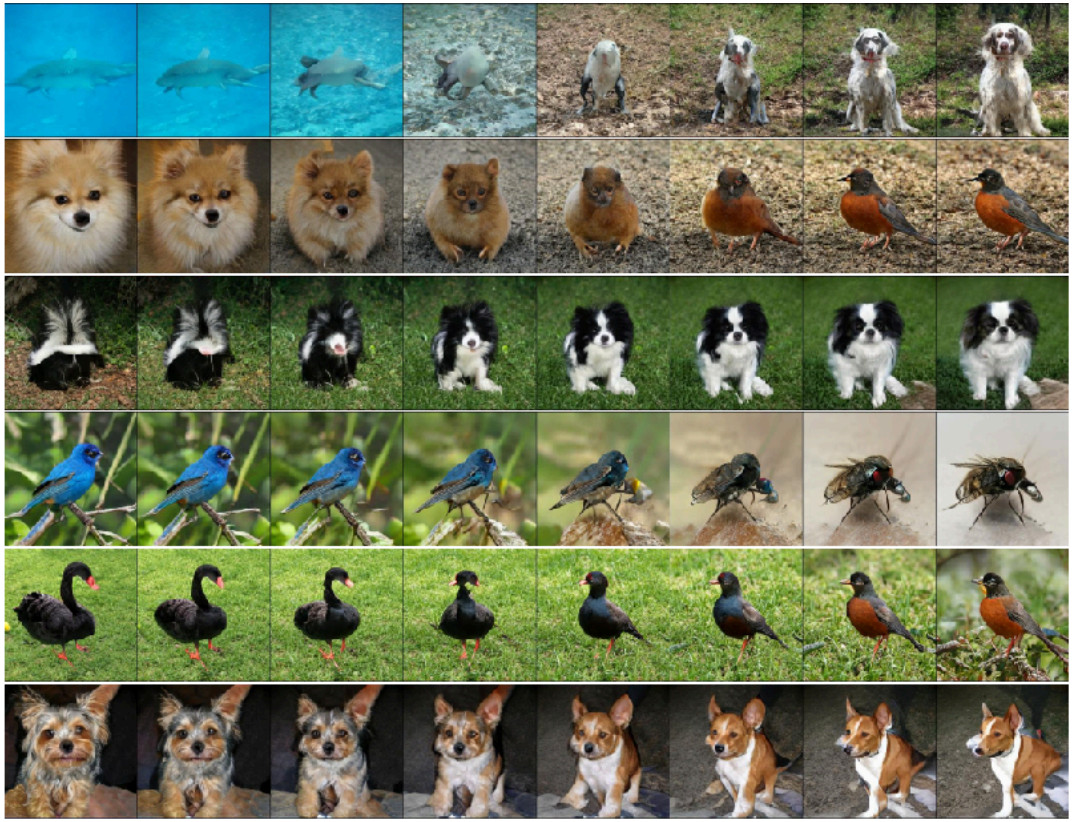
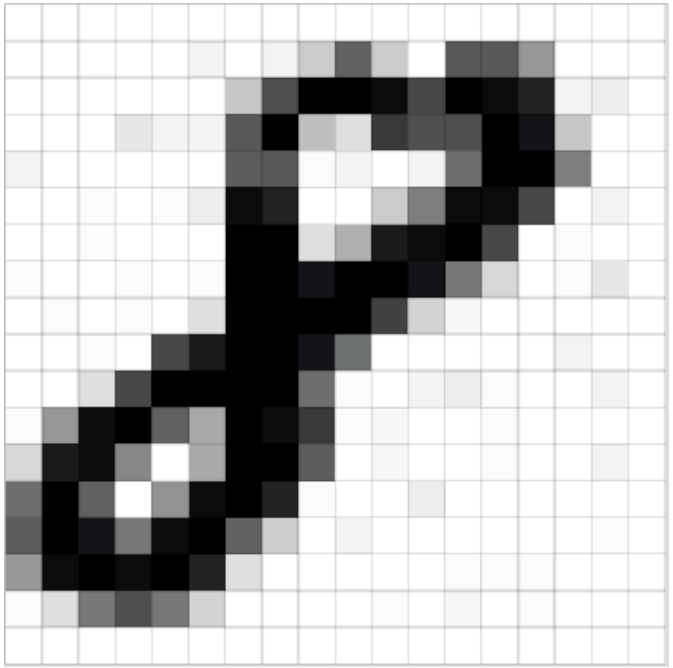
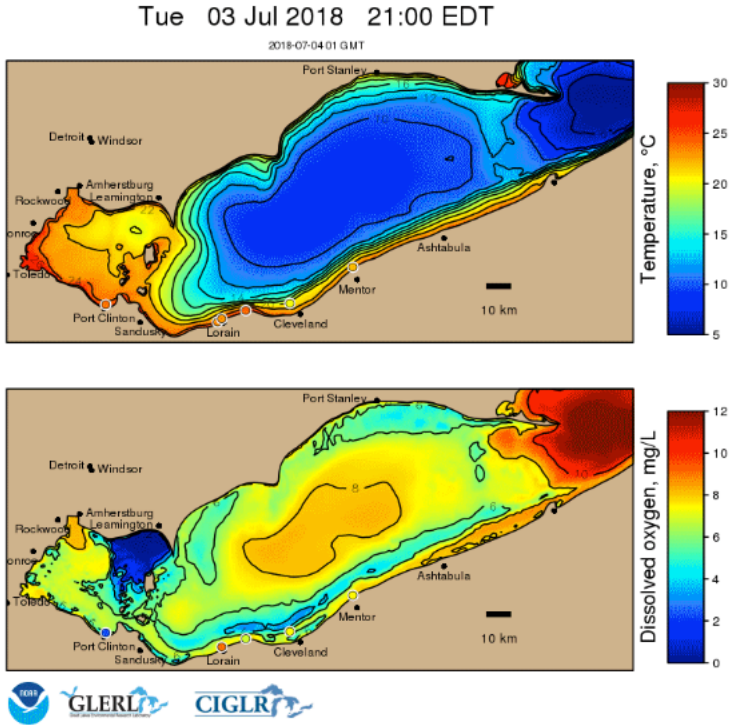


Figure 8: Interpolations between z, c pairs.

Brock et al, LARGE SCALE GAN TRAINING FOR HIGH FIDELITY NATURAL IMAGE SYNTHESIS, 2018

An image is a matrix of numbers





https://medium.com/@ageitgey/machine-learning-is-fun-part-3-deep-learning-and-convolutional-neural-networks-f40359318721

https://www.glerl.noaa.gov/data/

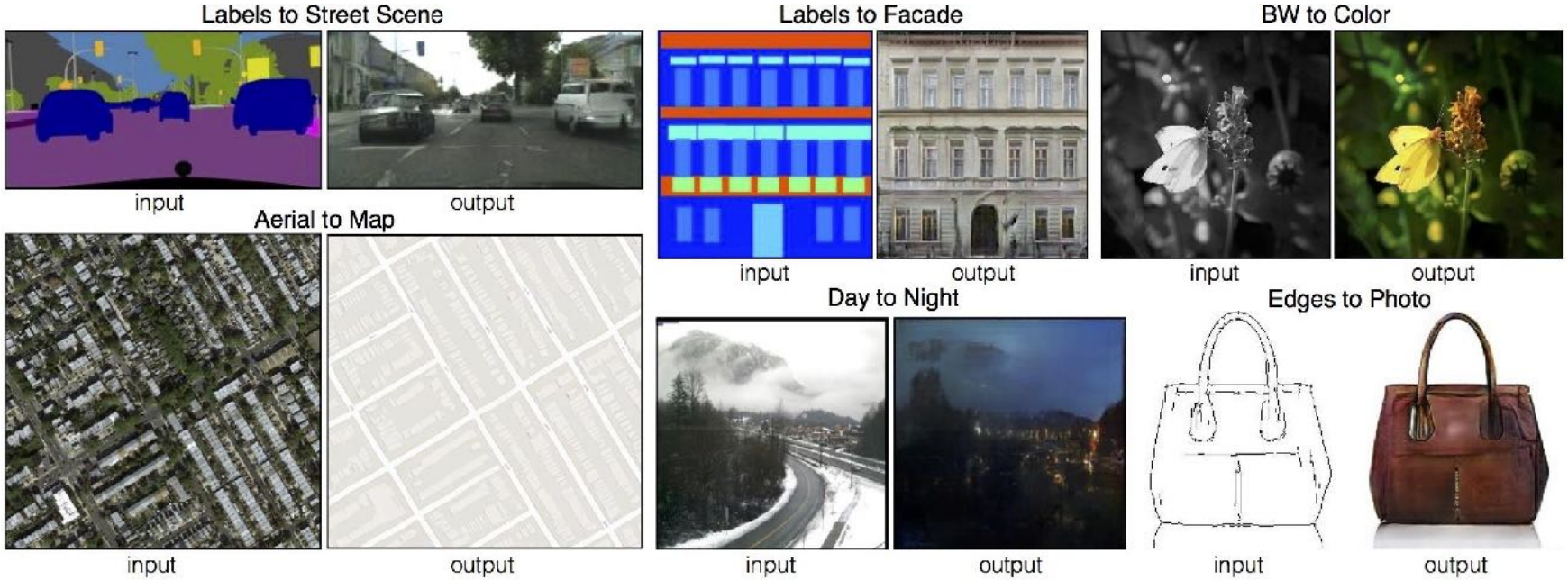
Paired translation: Pix2Pix ~400 Samples

Figure 8: Example results on Google Maps at 512x512 resolution (model was trained on images at 256 × 256 resolution, and run convolutionally on the larger images at test time). Contrast adjusted for clarity.

johanna.hansen@mail.mcgill.ca

Isola et al. Pix2Pix, 2018

Paired translation: Pix2Pix



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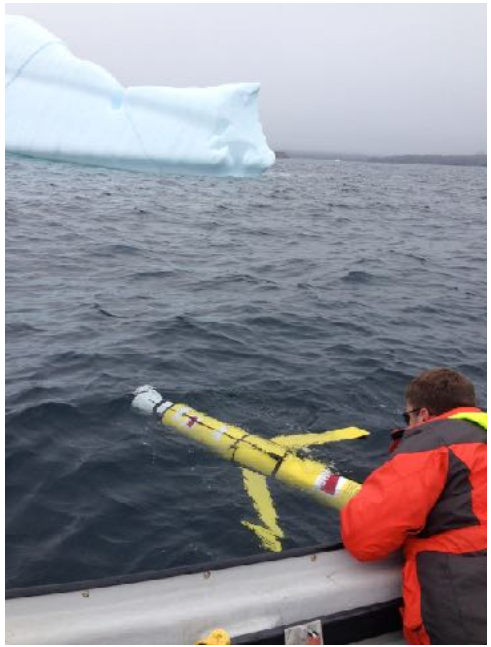
Isola et al. Pix2Pix, 2018



Zhou et al, “Towards Autonomous Underwater Iceberg Profiling using a Mechanical Scanning Sonar on a Underwater Slocum Glider”, 2016

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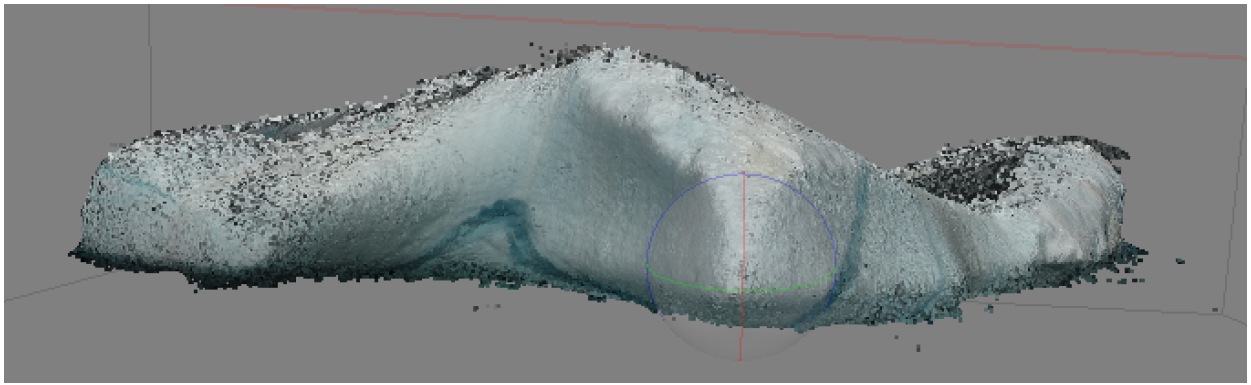
Geometry from Images



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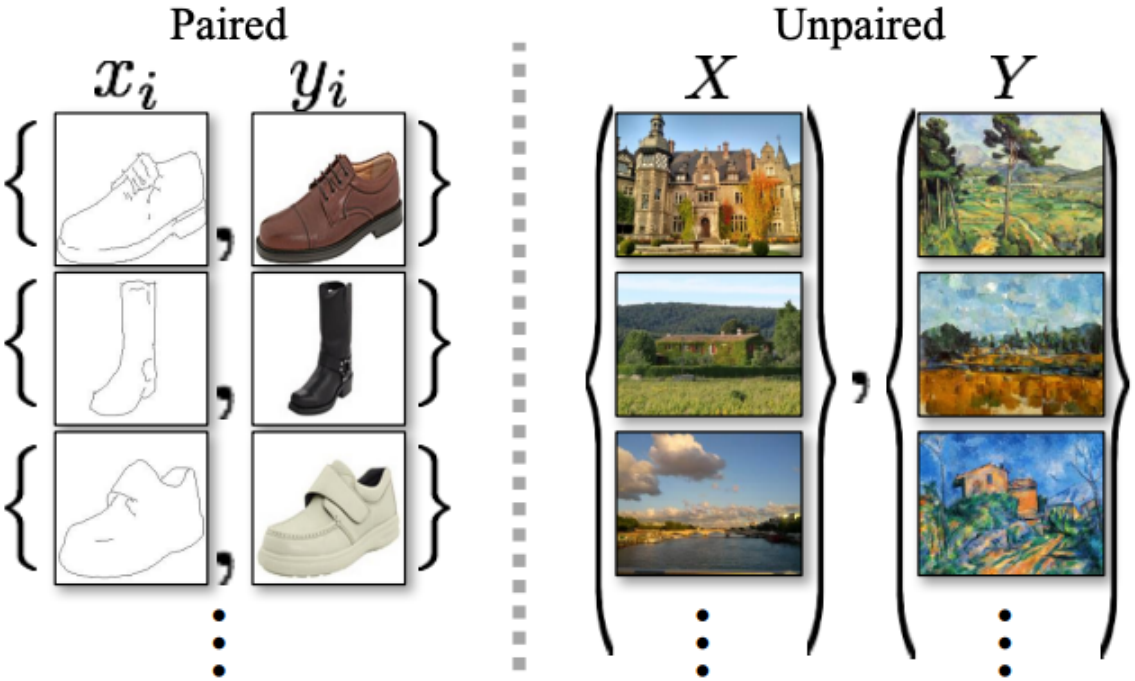
Unpaired Translation: CycleGAN



Zhu et al, Unpaired Image-to-Image Translation using Cycle-Consistent Adversarial Networks, 2017

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Unpaired Translation: CycleGAN

Zhu et al, Unpaired Image-to-Image Translation using Cycle-Consistent Adversarial Networks, 2017

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Learning Controllable Factors

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Ke Li & Jitendra Malik, “Implicit Maximum Likelihood Estimation”, 2018

Learned Super Resolution

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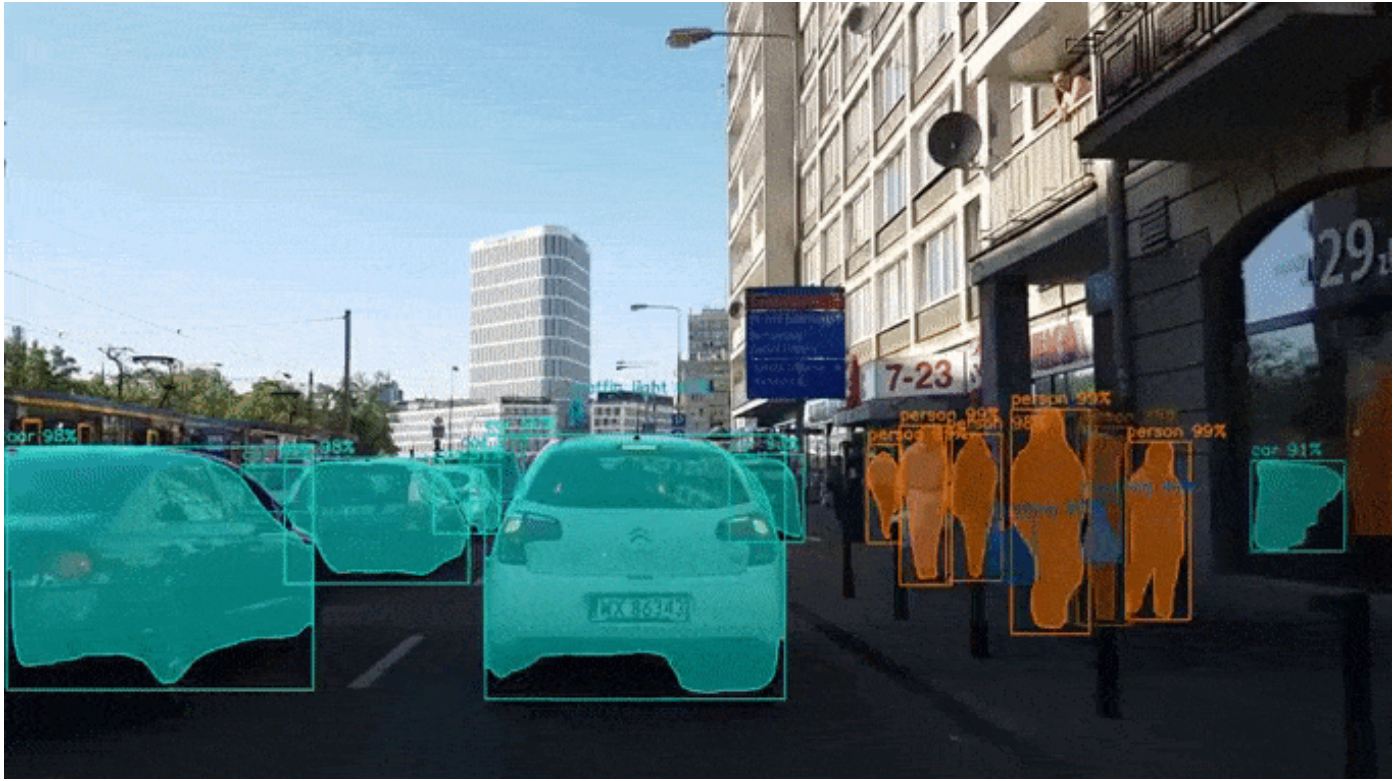
Ke Li & Jitendra Malik, “Implicit Maximum Likelihood Estimation”, 2018

Instance Segmentation



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He et al, “Mask R-CNN”, 2017

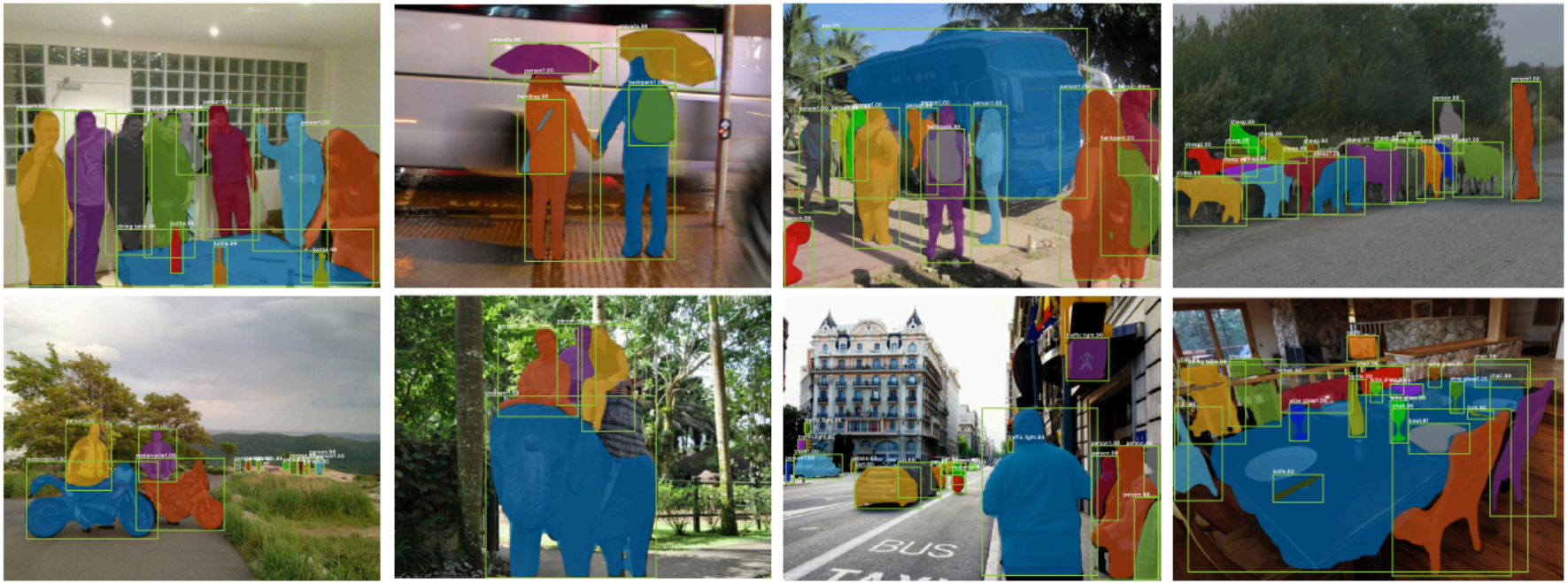

Figure 2. **Mask R-CNN** results on the COCO test set. These results are based on ResNet-101 [19], achieving a *mask* AP of 35.7 and running at 5 fps. Masks are shown in color, and bounding box, category, and confidences are also shown.

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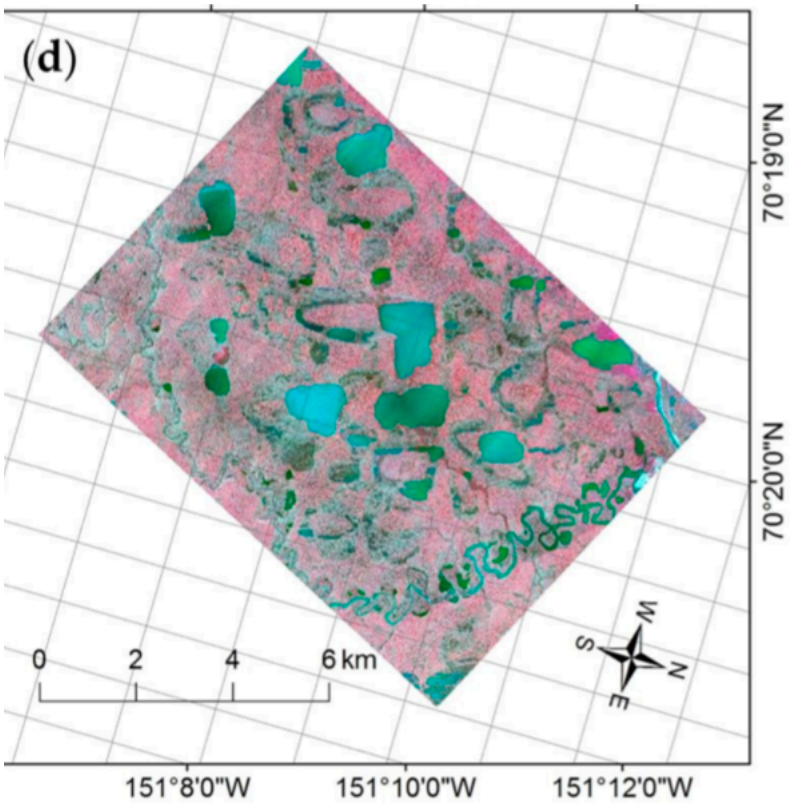
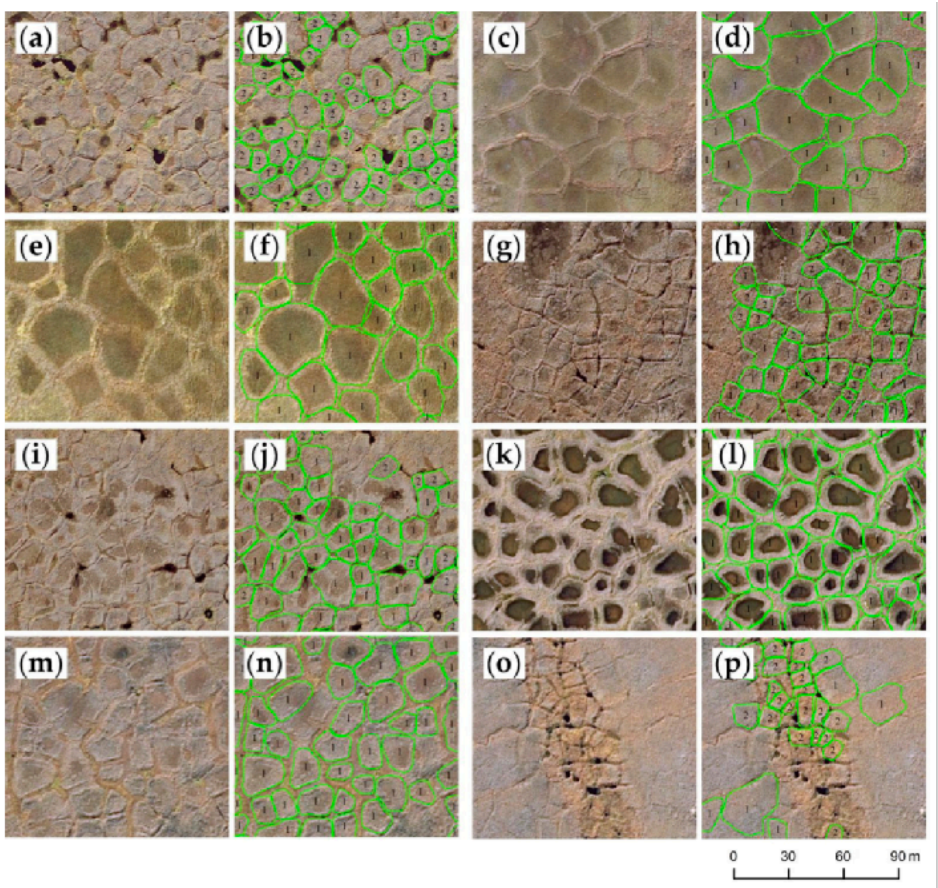
He et al, “Mask R-CNN”, 2017





Zhang et al, “Deep Convolutional Neural Networks for Automated Characterization of Arctic Ice-Wedge Polygons in Very High Spatial Resolution Aerial Imagery”, 2018

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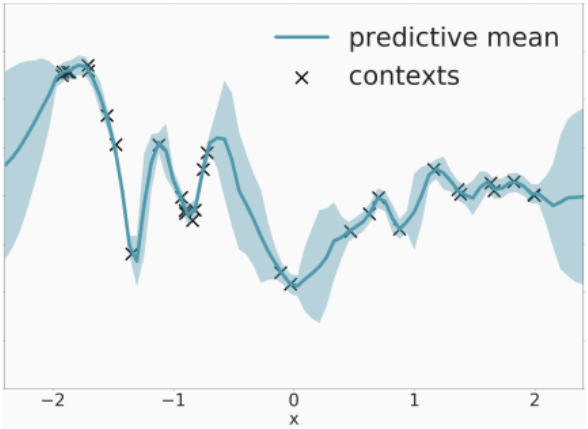
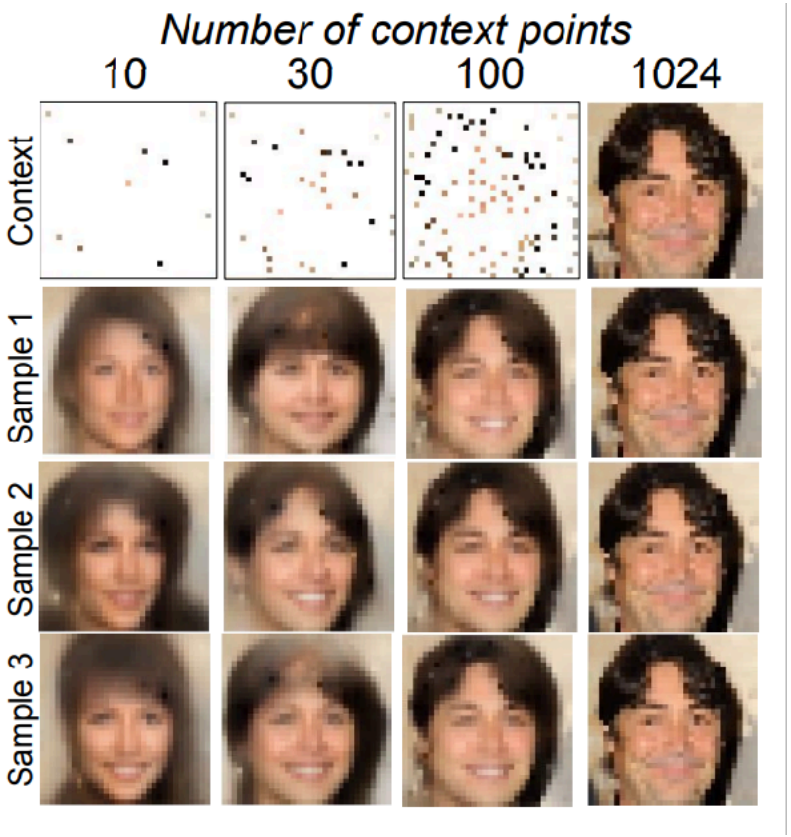
Learn to Model Complex Structures with Few Data Points





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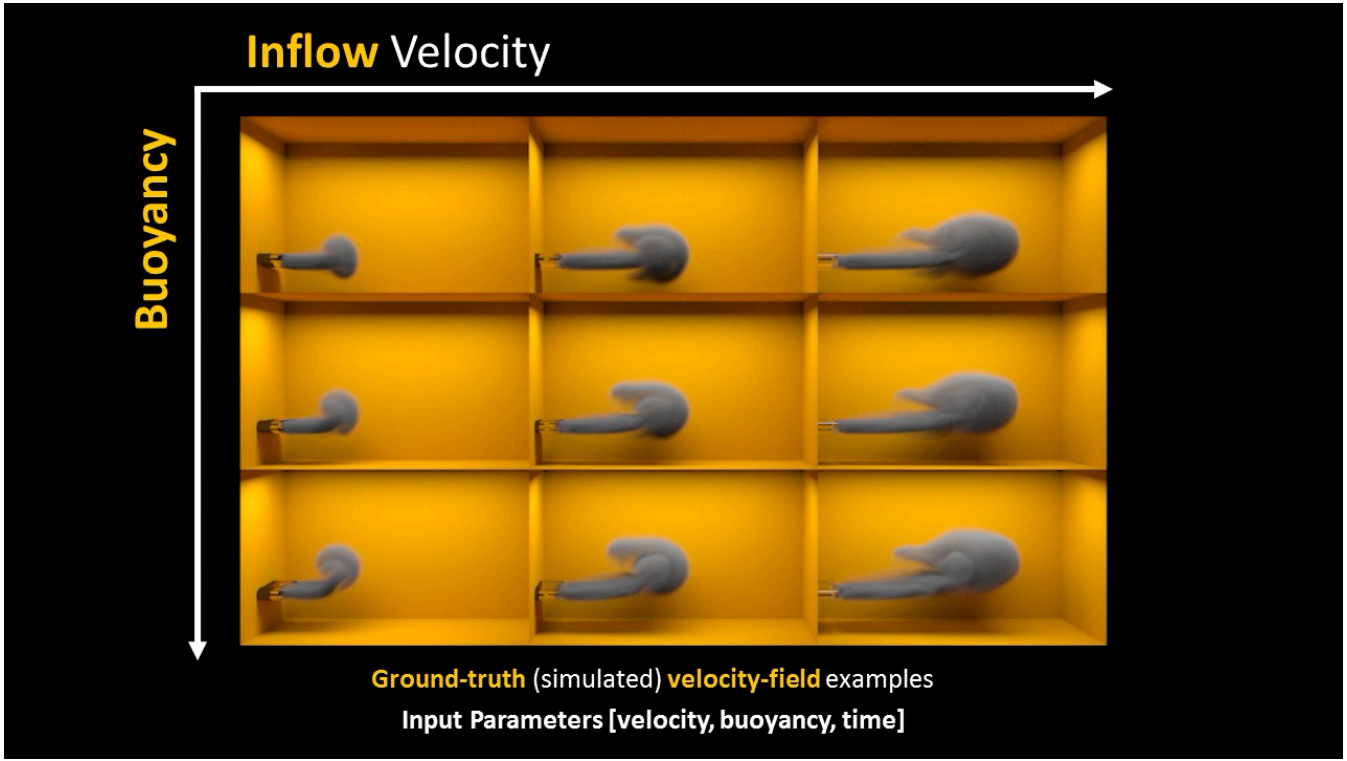
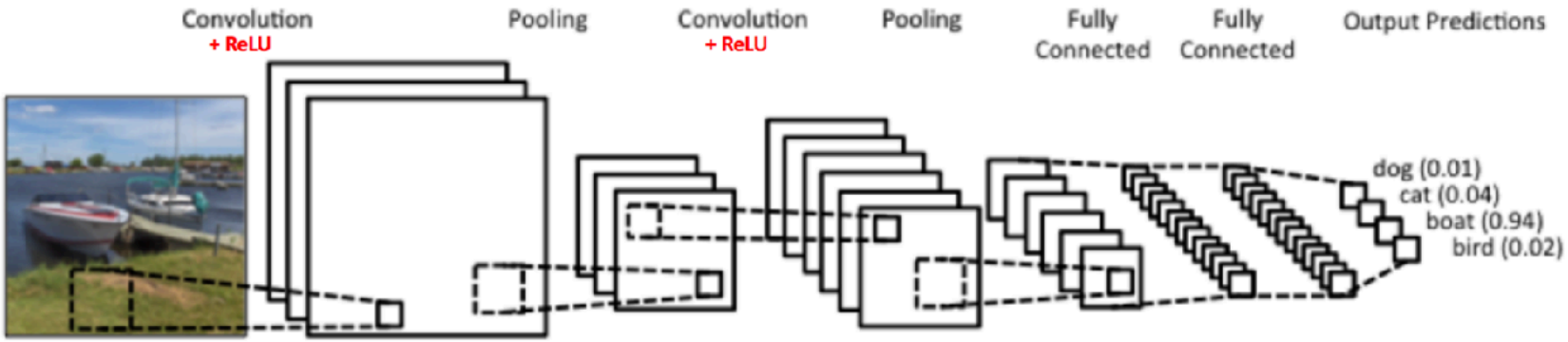
Kim et al, “Attentive Neural Processes”, 2019

Learning to Approximate Physics Calculations (700x Speedup)



Kim et al, Deep Fluids: A Generative Network for Parameterized Fluid Simulations, 2019

Deep Neural Networks



Source: https://ujjwalkarn.me/2016/08/11/intuitive-explanation-convnets/

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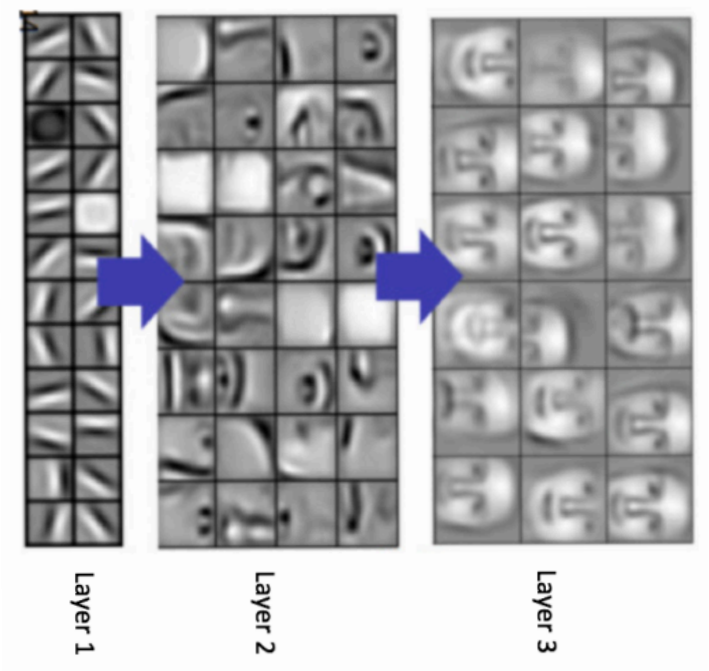
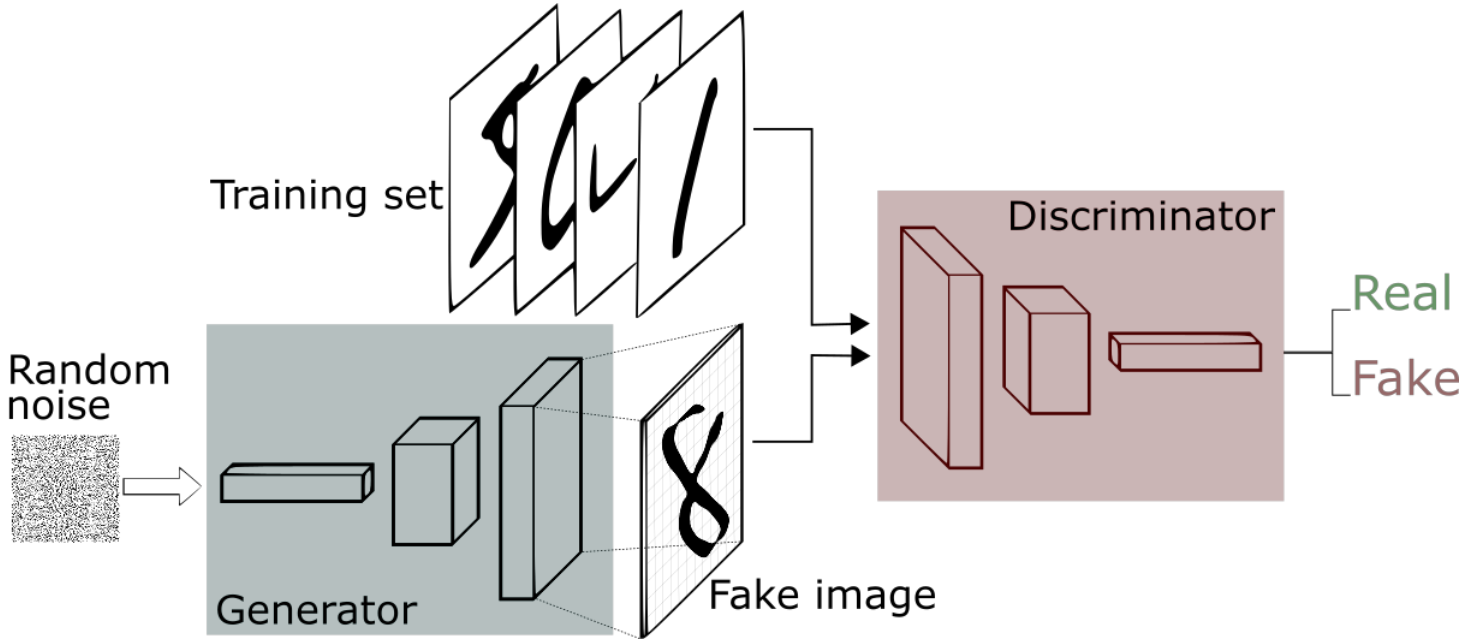
Feature Structure Convenient for Transfer



Lee et al, “Convolutional Deep Belief Networks for Scalable Unsupervised Learning of Hierarchical Representations”, 2009

Generative Adversarial Networks



Generative Adversarial Networks, Goodfellow et al, 2014, Photo Credit: Thalles Silva

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Model-based decision making for improved autonomy in scientific surveying robots.

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