Autonomy and AI

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Introduction

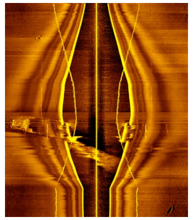
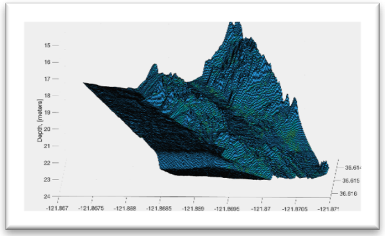
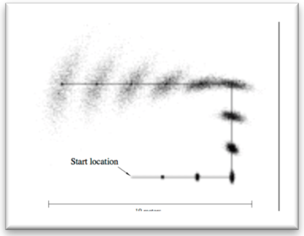
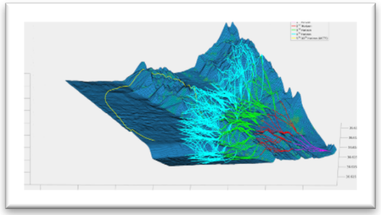
What I'm really going to talk about today is the ability of an unmanned mobile system to operate independently in a potentially unknown, dynamic environment.

The talk reflects the impact that AI/ML has had on robotics from the NPS CAVR lab historical perspective

I'll provide overviews of what I believe are the AI/ML mathematical constructs that are currently the basis for achieving greater autonomy for these robotic systems.

As you see the presentation, I'd encourage you to think critically – what are going to be the limitations of this approach?

Components of Robotic Autonomy

	Input	Function	Output
The Plant (the unmanned system)	Control input, Sensor measurements		Motion
Sensing	2/3D Image information		Processed data
Mapping	Processed sensor data Prior map data Vehicle pose		Updated Map
Position localization and estimation	Processed sensor data Prior map data Prior vehicle pose		Update pose with uncertainty
Path planning	Vehicle dynamics Map Goal objective		Path or trajectory

AUV Obstacle detection and avoidance (2005)

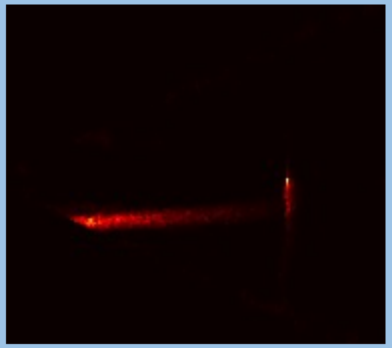
Path Planning

Calculus of Variations

The plant

Sensor Processing

Hough Transform



Vertical Forward-Looking Sonar

Position Estimation

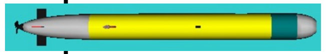
Extend Kalman Filter
(Optimal Estimation)

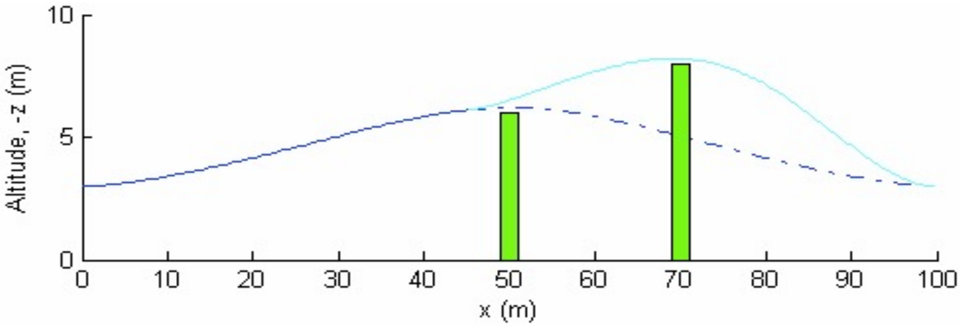
Map Estimation

N/A

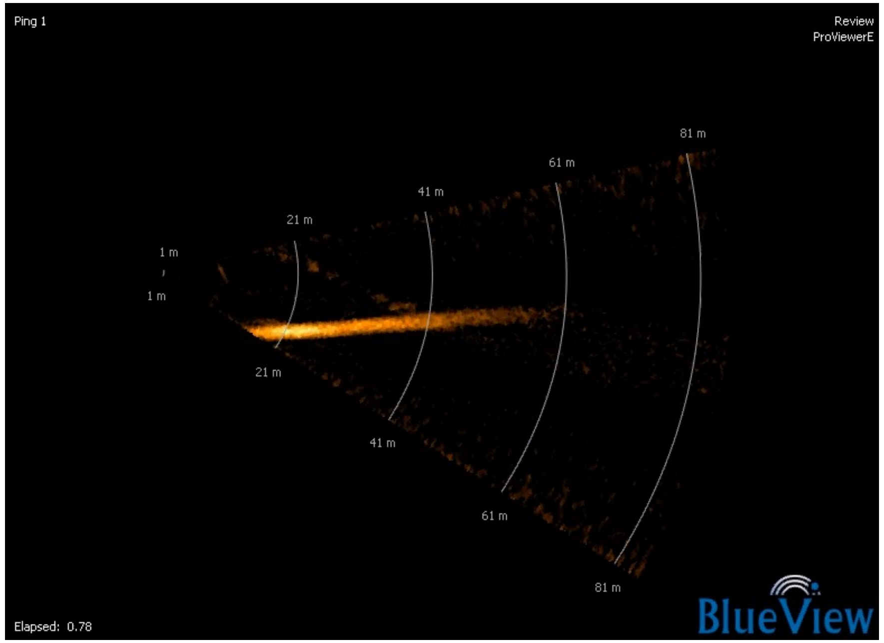
AUV Obstacle detection and avoidance (2005)

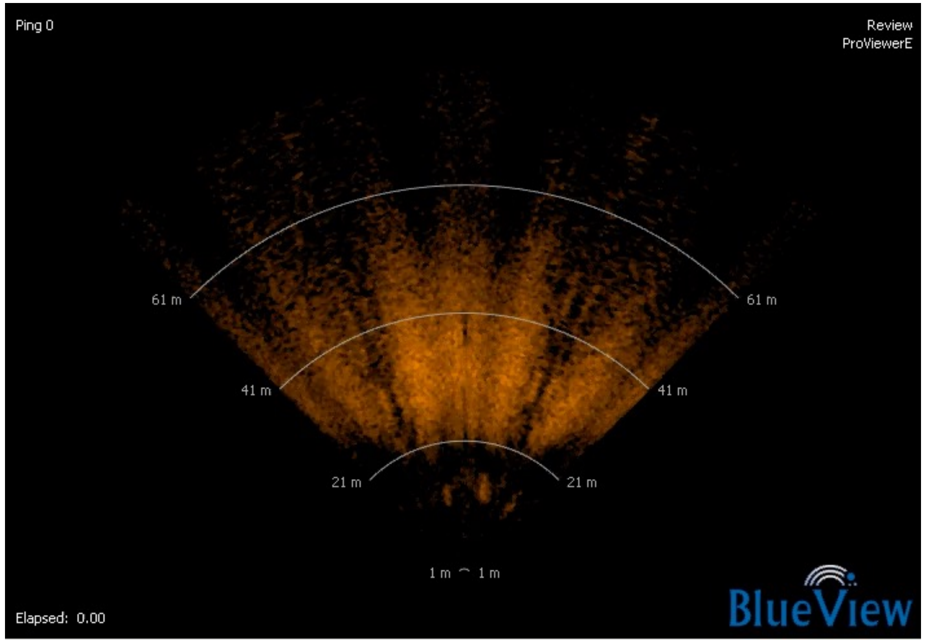
Trajectory Planning: Calculus of Variations





Importance of simulation: What is an obstacle





New autonomy example – Undersea Active Terrain Aided Nav (2020)

Description:

- GPS degraded or denied navigation solutions are required for current operational environments.
- Traditional Terrain Aided Navigation (TAN) is limited due to a requirement for a prior bathymetric map.
- This is limiting since frequently there is no prior map.

Solution:

- Active TAN - Dynamically build a map simultaneous with a bathymetric coverage mission.
- Balance exploration/exploitation using an information theoretic framework
- Exploration – emphasize search when confident about vehicle position.
- Exploit – emphasize localization on features when AUV position is poor

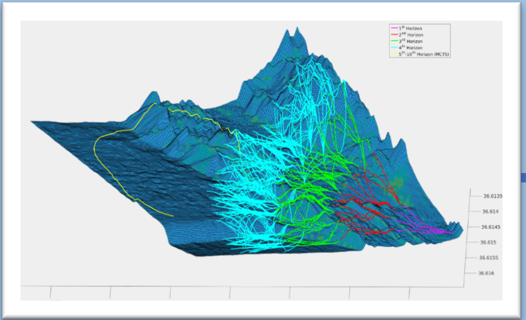
Application:

- Under ice – Use the ice topology as a map that can be used for position estimation.
- ICEX – Navy exercise run by the Arctic Submarine Lab once every two years
- 200 miles North of Prudhoe Bay, AK Northern most point of Alaska.
- Moving ice flow – 1 m/s, 24NM per day, non-linear motion

Evaluating the impact of AI/ML on robotic autonomy

Path Planning

Informational Entropy
- Exploration
- Exploitation

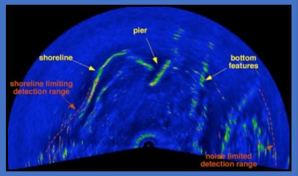


Partially Observable Monte Carlo Planning

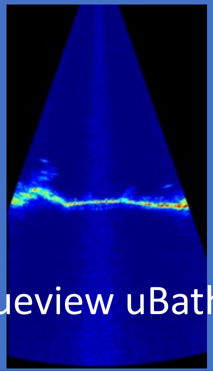
The plant

Self-assessment, "Self-awareness"

Sensor Processing



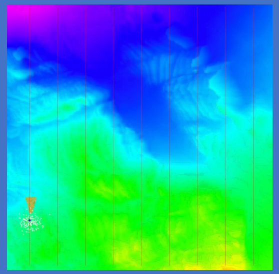
UTARL ATLAS



Blueview uBathy

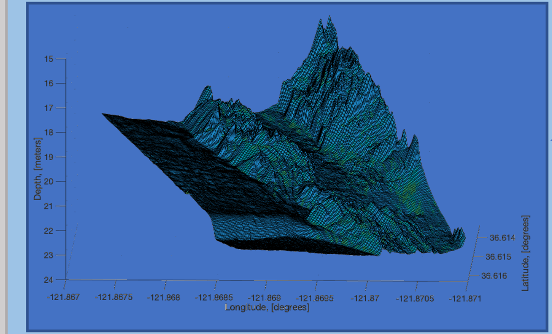
Multi-sensor fusion, CNNs

Position Estimation



Particle Filter

Map Estimation



Gaussian Process Model

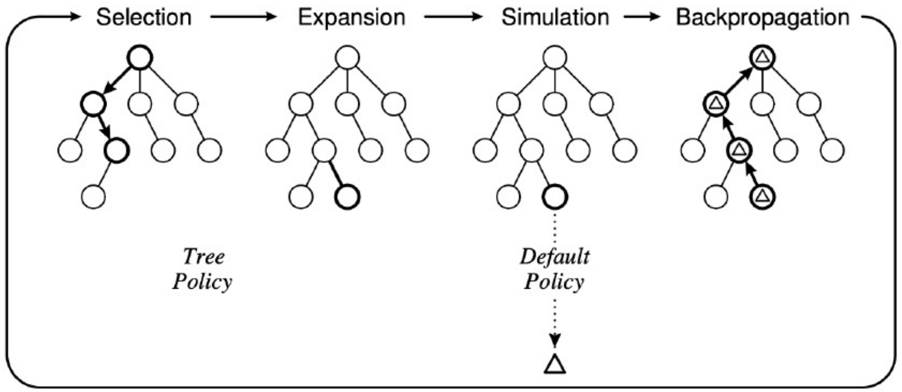
Partially Observable Monte Carlo Planning (POMCP) = POMDP + MCTS

$$Q_t(\mathbf{b},\mathbf{a}) = \rho(\mathbf{b},\mathbf{a}) + \gamma \int_{\mathbf{z}'\in\mathbb{Z}} \eta(\mathbf{z}'|\mathbf{b},\mathbf{a}) V^*_{t-1}\tau(\mathbf{b},\mathbf{a},\mathbf{z}')d\mathbf{z}'$$

$$V^*_t(\mathbf{b}) = \sup_{\mathbf{a}\in\mathbb{A}} Q_t(\mathbf{b},\mathbf{a})$$

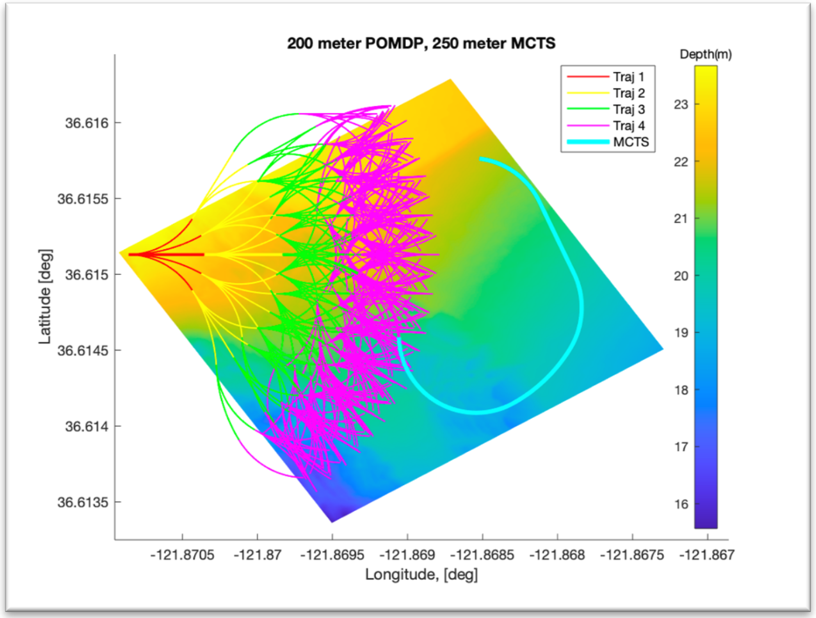
$$\pi^*_t(\mathbf{b}) = arg\ \sup_{\mathbf{a}\in\mathbb{A}} Q_t(\mathbf{b},\mathbf{a}),$$

Partially Observable Markov Decision Process (POMDP)

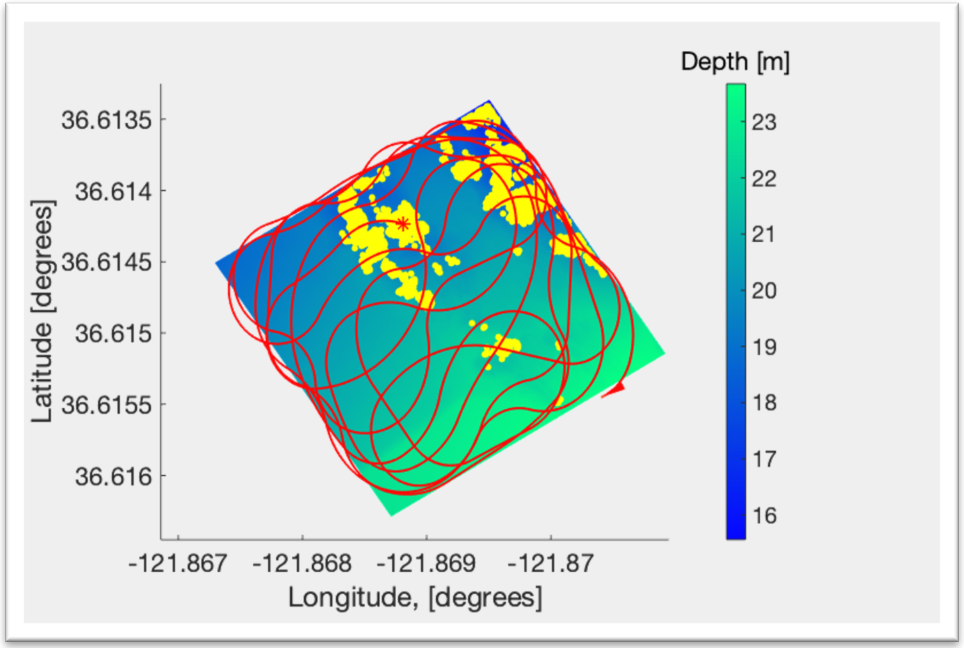


UCB1

Monte Carlo Tree Search (MCTS)



Planning Example

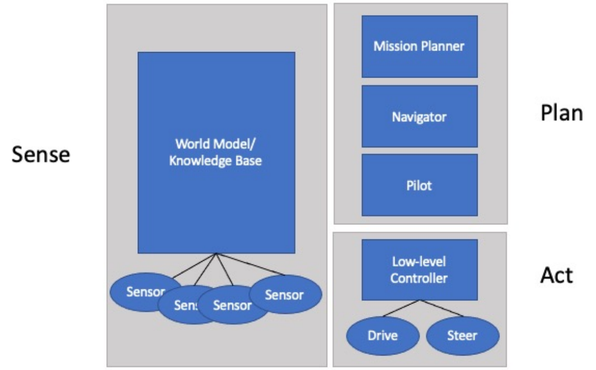


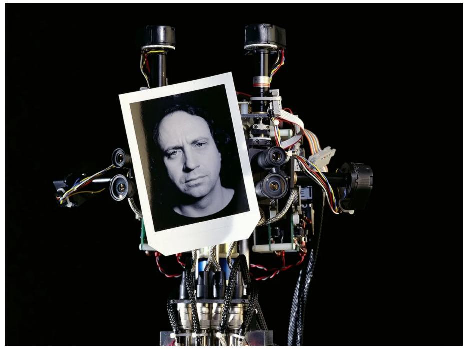
Back to the future – integration of multiple behaviors

So far, I’ve shown 2 examples of autonomy. Each could be considered a behavior – one for obstacle detection and avoidance and a second for area coverage.

How does a control/software architecture handle prioritization of multiple (potentially competing) behaviors?

Historically





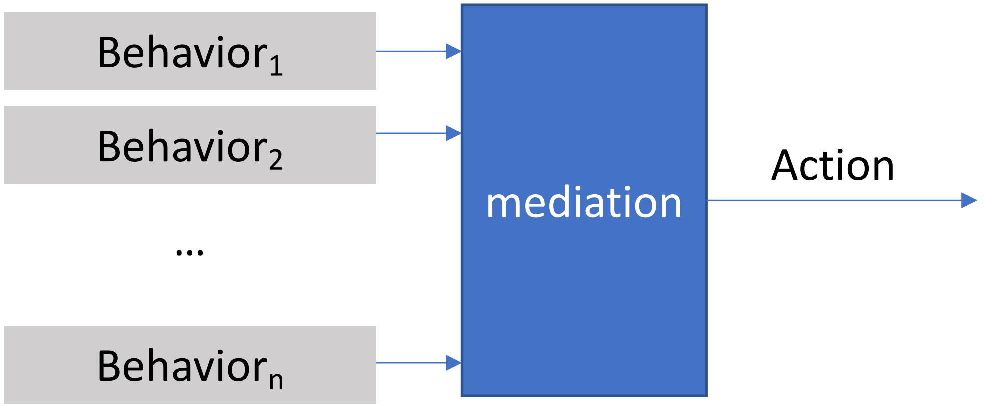
[Rodney Brooks MIT]

Behavior-based architectures

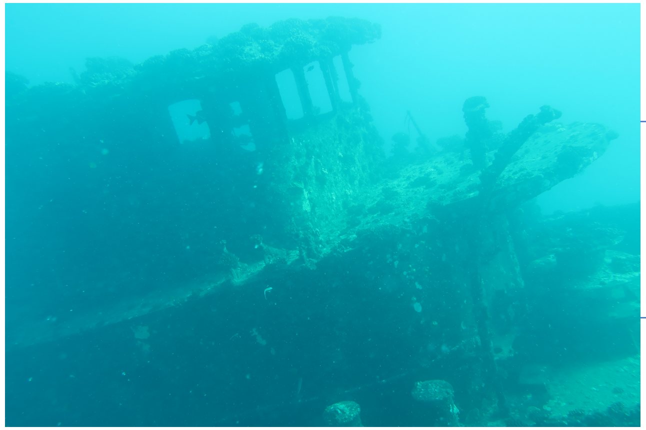
- Subsumption
- Action selection
- Motor schemas

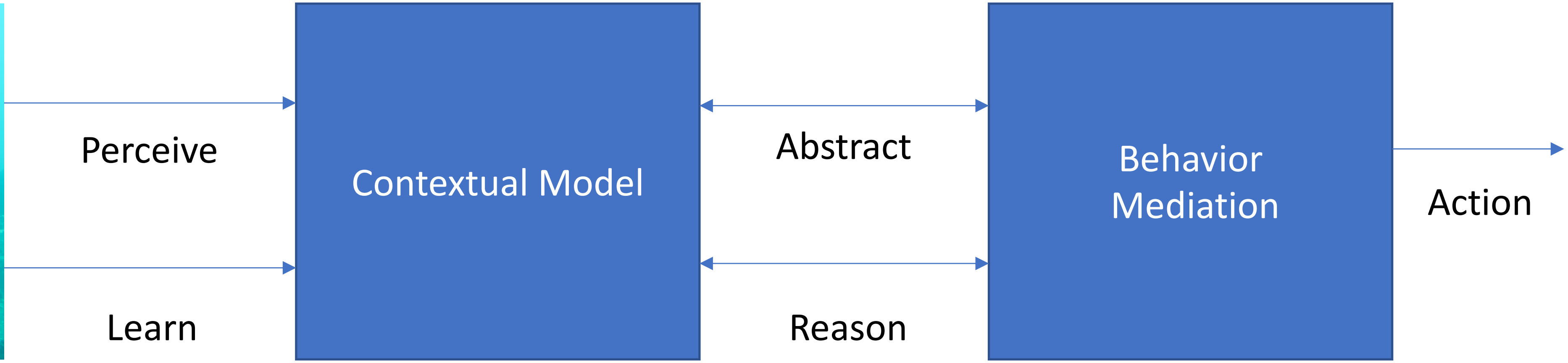
Approaches with AI/ML

- Multi-objective Optimization
- Integration of ML techniques with Semantic Inference
  - Contextual Adaptation



Robotic Contextual Model





USS Nashua, Oahu, HI

As an alternative to sense-plan-act

Conclusions

- In the last 15 years AI/ML techniques have infiltrated the robot autonomy feedback
    - Sensor processing
    - Mapping
    - Position Estimation
    - Self-awareness
    - Path planning
- On the importance of data and simulation
- Limitations associated with current AI/ML techniques
- On the importance of operational context and data inference
- A final comment on networked systems