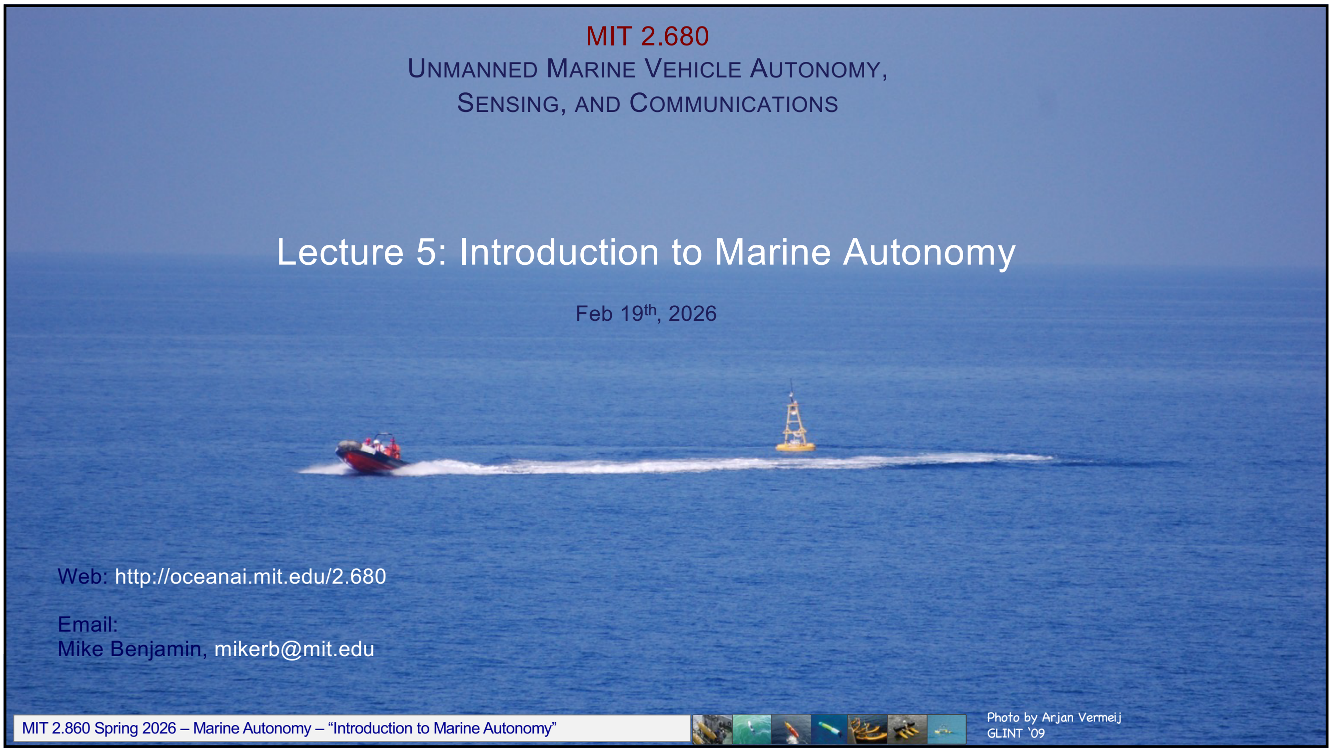

1

In this Lecture

- What is Artificial Intelligence? What is Autonomy?
- How does autonomy scale? What are the easy and hard versions?
- What are some marine robot missions? What level of autonomy do they need?
- What is an autonomy architecture?
- What is action selection? How does a robot choose its next action?
- An introduction to the IvP Helm autonomy.

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What is Artificial Intelligence?

AI textbooks define the field as "*the study and design of intelligent agents*" where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success. - Wikipedia

AI is the ability of a computer or other machine to perform those activities that are **normally thought to require (human) intelligence**. – Answers.com

(Once a machine can do it, it no longer requires human intelligence, and it is no longer an example of Artificial Intelligence)

Are the following examples of AI?

- The logic in an elevator controller?
- A calculator?
- An ATM?
- Computer chess?
- A computer jeopardy contestant?
- Facial Recognition System?
- Siri? ChatGPT?

At some point in history each was considered the domain of humans.

GPT-4.5 & LLaMa 3.1:
"Just a text predictor"
Have passed the Turing Test (not yet ~AGI)
"Trained to make up things that look like facts" [13]

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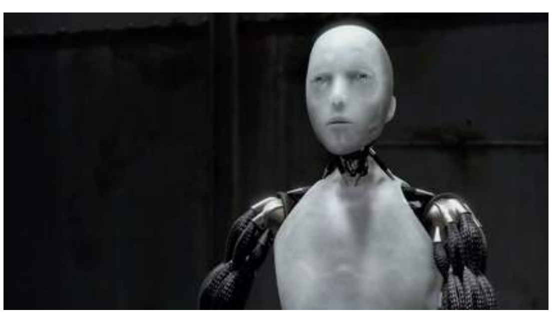
"Artificial Intelligence" vs "Autonomy"

There is no widely accepted definition of either, or their difference.
My personal view:

Artificial Intelligence (Hollywood)



Human level language dialog, curiousity, human level vision, mobility, dexterity, independent thought, initiative….

Autonomy (Industry)

Mobility, proper reaction to sensed danger, Detection, classification and reporting of sensed phenomena.

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"AI" vs "Autonomy" vs "Automation"

NBC News: Chinese Humanoid Robots Take Center Stage for Lunar New Years Celebration
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"AI" vs "Autonomy" vs "Automation"

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"AI" vs "Autonomy" vs "Automation"

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The "Autonomy Roadmap"

- You have to have a plan to show your investors
- It should be easy to see the progression
- It should convey confidence that 85+% of the plan can be achieved in the time/money alotted.

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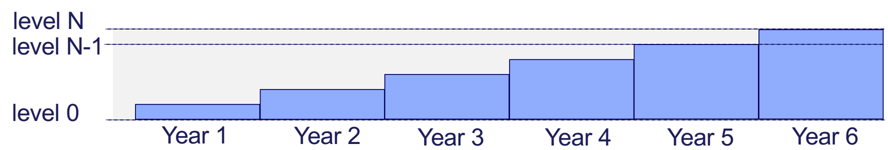
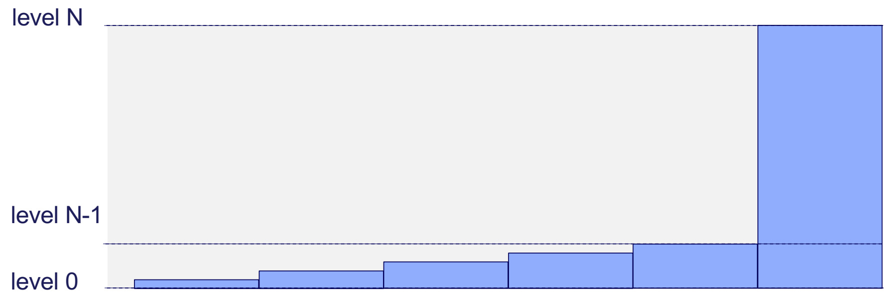
Linear vs Exponential Roadmaps

Ideally, a roadmap should be ***linear***, each year adding the same amount of capability requiring the same amount of effort/cost.



With some technologies it is difficult to judge the gap between two levels of capabilities. An ***exponential*** roadmap is heavy on late stages.



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Roadmap for USV Autonomy

What is wrong with this roadmap?

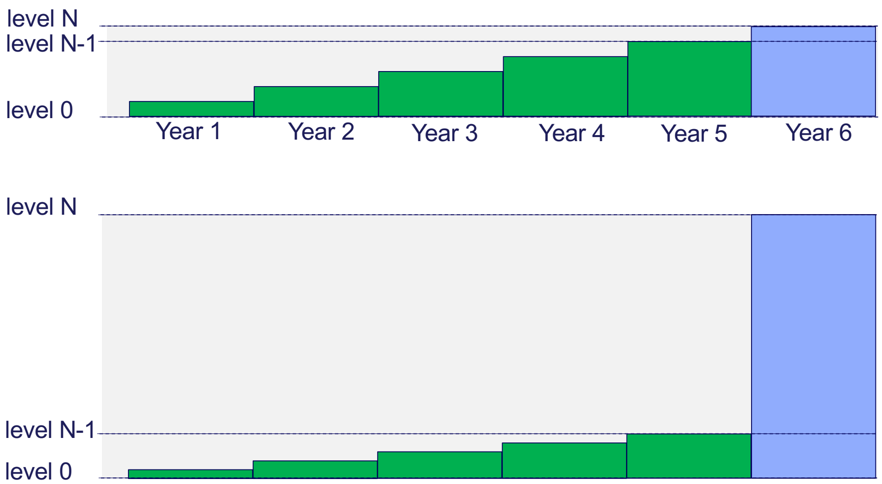
Year 1: Build the Vehicle

Year 2: Enable Remote Control

Year 3: Autonomous Control

10

Assessing the Investment



Done

Not Done

We're on our way: keep investing!

Technology was over-promised.

"But wait – I accomplished 5/6 of my goals!"

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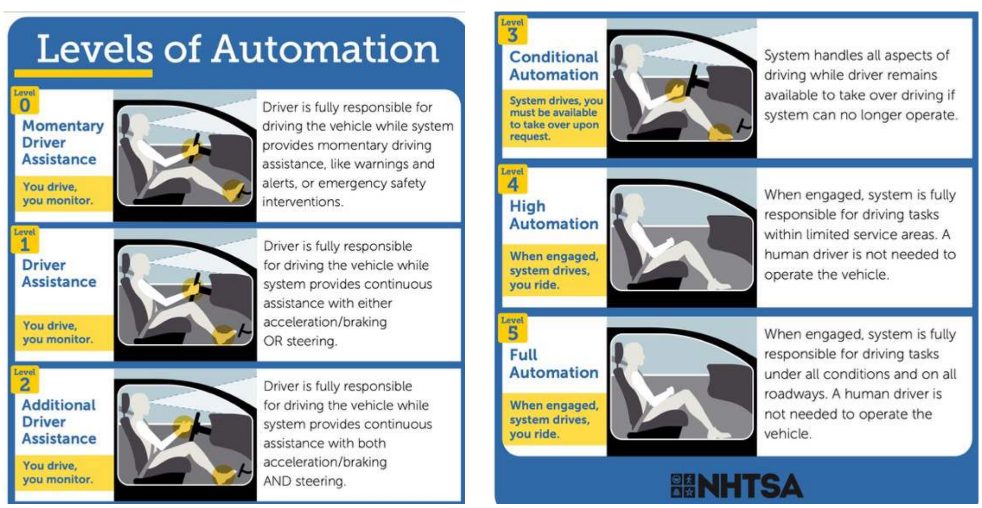
Levels of Automation for Driving

National Highway Traffic Safety Administration (NHTS)



Feb 8th, 2026: https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-05/Level-of-Automation-052522-tag.pdf

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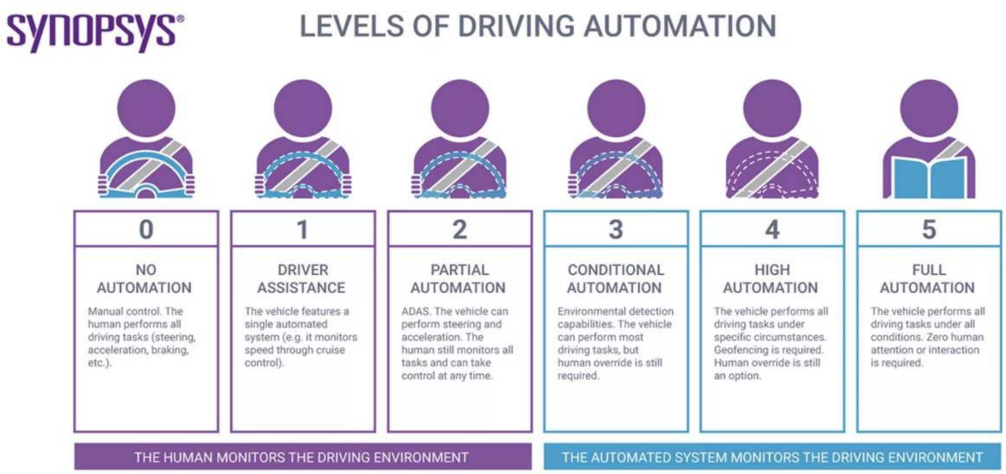
Levels of Driving Autonomy



Feb 8th, 2026: https://www.synopsys.com/blogs/chip-design/autonomous-driving-levels.html

Which Cars are capable of Level 5 Autonomy?

None [1]

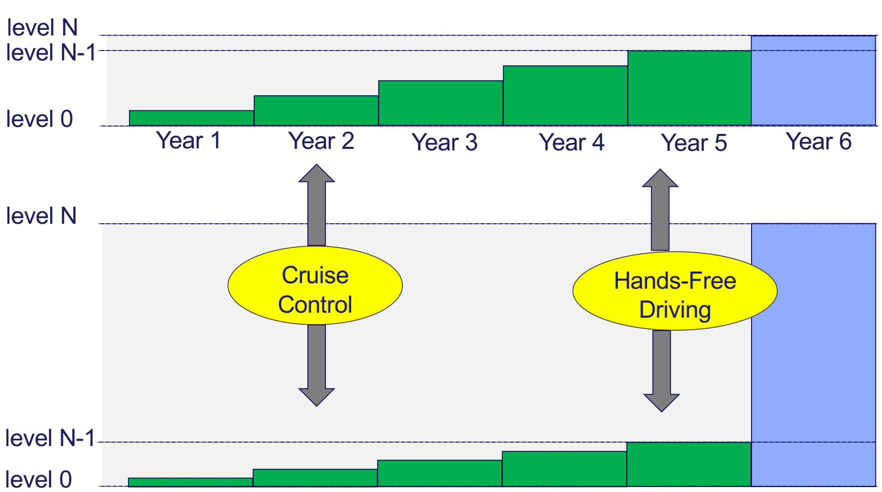
Arguably the hardest technical challenge in history [1]

Summary Table

Level	Capability	Key Examples (2026)
Level 2	Hands-on or Hands-off (Supervised)	Tesla FSD, Ford BlueCruise, GM Super Cruise
Level 3	Eyes-off (Limited conditions)	Mercedes-Benz DRIVE PILOT
Level 4	Driverless (Geofenced areas)	Waymo, Zoox, Tesla Cybercab (upcoming)
Level 5	Driverless (Everywhere/Anywhere)	**None exist yet**

Driver Assist (2004)

Assessing the Investment



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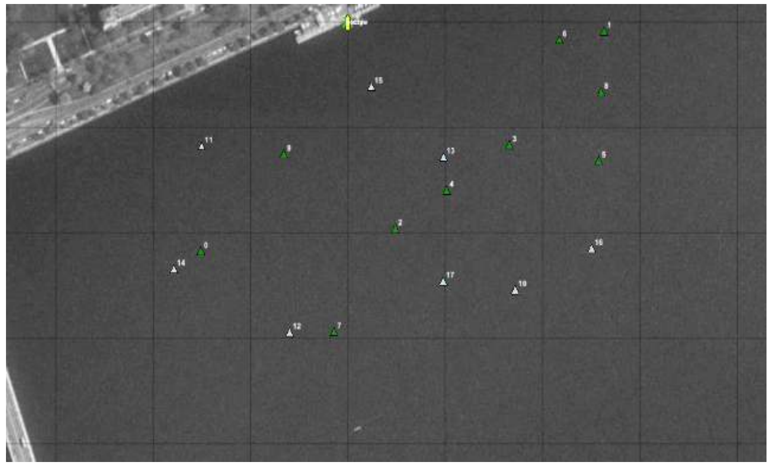
What is the Role of Autonomy in Unmanned Marine Vehicles?

Is a vehicle that navigates to a set of pre-determined waypoints, and surfaces, an example of marine autonomy?

This is an important class of autonomy missions, but it is not:

- adaptive (to the environment, other vehicles, or commanders), nor is it
- collaborative (it may be co-deployed, but does not consider other vehicles.)



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Marine Vehicle Autonomy Roadmap

The roadmap for marine vehicle is less about replacing the human, and more about giving the robot a greater ability to act upon sensed events, and comms to other robots, to alter its mission.

Scripted → Adaptive → Collaborative

Scripted
- Pre-determined Path or event sequence
- No Sensor Input other than navigation, e.g. GPS
- Pre-determined mission completion based on event sequence or time

Adaptive
- Mission based on modes, not fixed event sequences
- Modes determined by sensed events
- Path adjustment based on obstacles or other vessels.

Collaborative
- Co-Deployed, Oblivious
- **In-Comms, dynamically deciding roles**
- **In-Comms, dynamically deciding roles, building joint world view from shared sensor data.**

Scripted vs. Adaptive Autonomy in Marine Vehicles

1. Better on-board sensing
2. Better autonomy algs
3. Lower-cost platforms enable multi-vehicle ops
4. Longer durations

The Trends

1. Lower cost platforms
2. Collision detection autonomy
3. Better comms to operators
4. Better navigation algs
5. More Investment in V&V, Testing

More efficient performance

Ease in recovery
Ease in deployment
Less risk of vehicle loss
Easier to Test and Validate

Adaptive, Collaborative Autonomy

Scripted Autonomy

Marine Vehicle Autonomy Roadmap

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Minesweeping

Minesweeping is the practice of the removal of explosive naval mines, usually by a specially designed ship called a minesweeper using various measures to either capture or detonate the mines, but sometimes also with an aircraft made for that purpose. [2]

A ***sweep*** is either a contact sweep, a wire dragged through the water by one or two ships to cut the mooring wire of floating mines, or a distance sweep that mimics a ship to detonate the mines.[2]

An MH-53E of the United States Navy towing an MK105 mine sweeping sled [4].

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Avenger Class Ships

The hulls of the *Avenger*-class ships are constructed of wood with an external coating of fiberglass. The wood used is oak, Douglas fir and Nootka Cypress because of their flexibility, strength and low weight. This construction allows the hull to withstand a nearby blast from a mine, and also gives the ship a low magnetic signature. [3]

Avenger-class mine countermeasures ship. [3]

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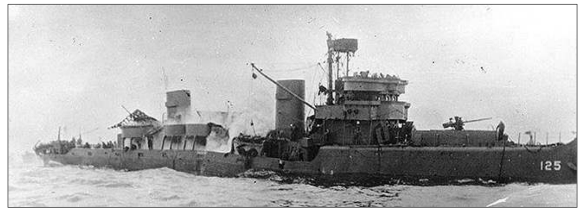
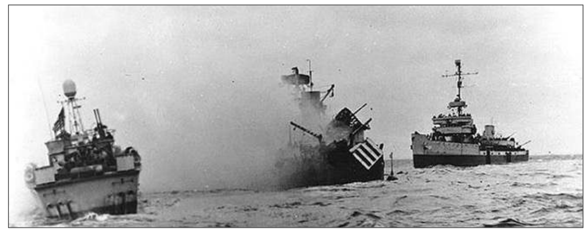
USS Tide (AM-125)

USS *Tide* (AM-125) was an *Auk*-class minesweeper On the morning of June 7th 1944, *Tide* swept the area inshore and between Îles Saint Marcouf and Barfleur to clear lanes for fire-support ships. At 09:40, while recovering her gear, *Tide* drifted over the Cardonet Banks and struck a mine which exploded with such force that she was lifted out of the water. The explosion broke her back, blasted a tremendous hole in her bottom, and tore away all bulkheads below the waterline causing immediate and irreversible flooding. *Tide*'s commanding officer — Lt. Cdr. Allard B. Heyward — died soon after the initial explosion.



Minesweeper USS Tide (AM-125) after striking a mine off Utah Beach, 7 June 1944. Note her broken back, with smoke pouring from amidships [5].



USS *Tide* sinking off "Utah" Beach after striking a mine during the Normandy invasion, 7 June 1944. *PT-509* and *Pheasant* are standing by. Photographed from *Threat [5]*.

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USV Minesweeping

The Common Unmanned Surface Vessel (CUSV)

The **Common Unmanned Surface Vessel (CUSV)**, is an unmanned surface vessel designed for the United States Navy to be deployed from *Freedom* and *Independence*-class littoral combat ships and intended to conduct mine and anti-submarine warfare missions.[6]

U.S. Navy and industry partners are currently testing the Unmanned Influence Sweep System (UISS) for its mine countermeasures mission. Published by NAVSEA PA (Public Affairs), March 2017, [7].

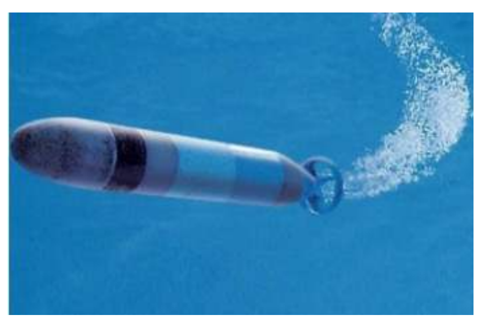
USV Minesweeping

Thales UK Halcyon USV

MK39 Expendable Mobile ASW Training Target (EMATT)

- Small UUV dynamic submarine-like target equipped with both acoustic and non-acoustic signatures [8].
- Over 12,000 produced for the US and international navies [8].

“Add realism by programming your EMATT’s course, depth, speed, time and passive tonal changes. Program your EMATT to automatically maneuver in response to active sonar interrogations.”



[8] https://www.lockheedmartin.com/content/dam/lockheed/data/ms2/documents/MK-39-productcard.pdf

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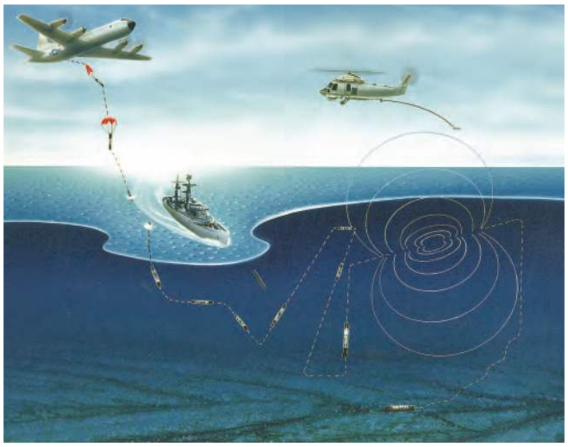
MK39 Expendable Mobile ASW Training Target
(EMATT)



EMATT Operational Sequence [8].

"Add realism by programming your EMATT's course, depth, speed, time and passive tonal changes. Program your EMATT to automatically maneuver in response to active sonar interrogations."

EMATT Deployed from a plane, Nov 2012, [9].

[8] https://www.lockheedmartin.com/content/dam/lockheed/data/ms2/documents/MK-39-productcard.pdf
[9] https://www.youtube.com/watch?time_continue=6&v=qpHOH7Or35s

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Scripted vs Adaptive Autonomy

- Pre-determined Path or event sequence
- No Sensor Input other than navigation, e.g. GPS
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- Modes determined by sensed events
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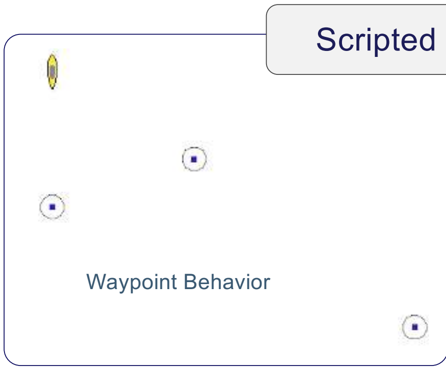
Scripted



Adaptive

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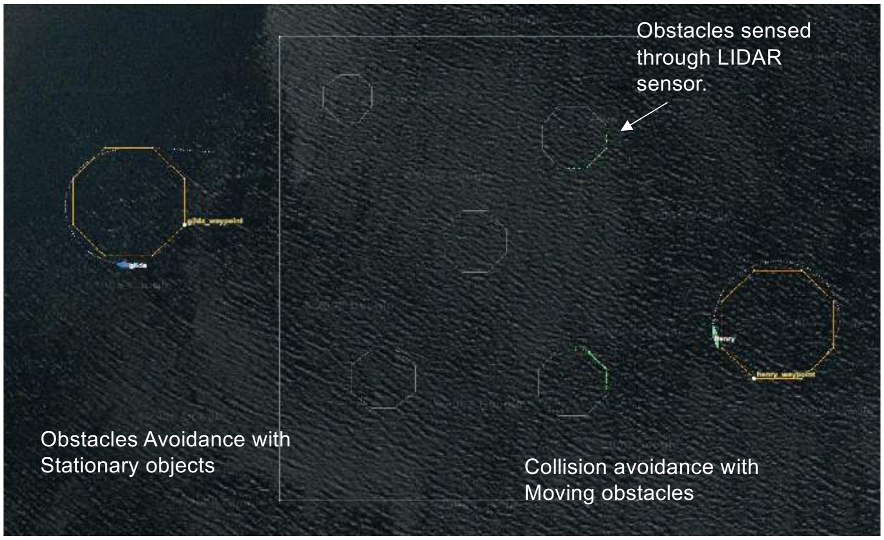
More Adaptive Autonomy

Vehicles switch between East/West Loiter Regions



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Collaborative Autonomy

Adaptive:
- Vehicles avoid each other
- Vehicles may switch modes based on events

Collaborative:
- Share joint responsibility for encircling the HVA
- Adjust speed to maintain even spacing
- Reach consensus on best vehicle to investigate points of interest

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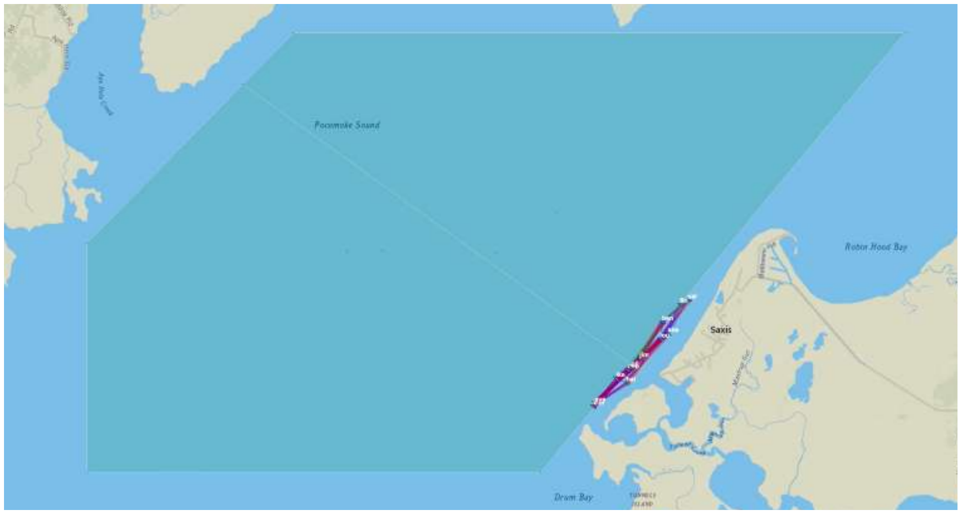
Collaborative Autonomy

Adapative:
- Vehicles share position information
- Adapt position based on

Collaborative:
- Shared goal of evenly distributed positioning
- Field will adjust to failures of some vehicles, or additional vehicles entering the field.



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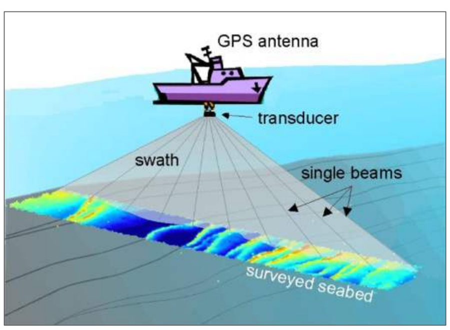
Hydrographaphic Surveys

Hydrographic survey is the science of measurement and description of features which affect maritime navigation, marine construction, dredging, offshore oil exploration/offshore oil drilling and related activities, [11].



[10]

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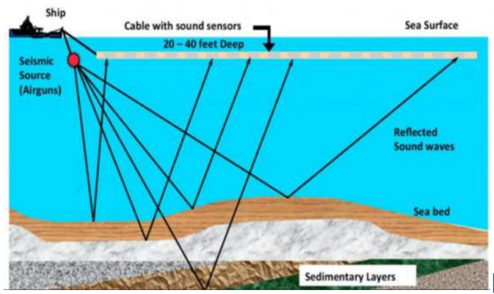
Seismic Surveys

A **seismic survey** is a method of investigating the subterranean structure, primarily used in search of oil and gas deposits. Marine seismic surveys have been performed since the 1950s when chemical explosives were used to create sound waves. In the 1960s airguns were developed and are now currently used for almost all seismic surveys, [11].



[11]

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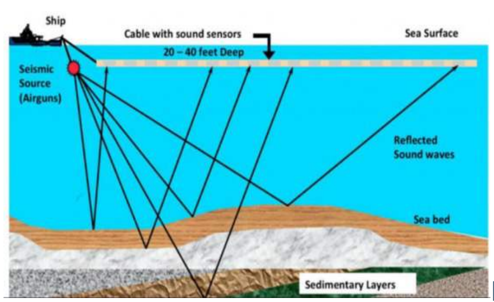

[11]

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Autonomy Architectures

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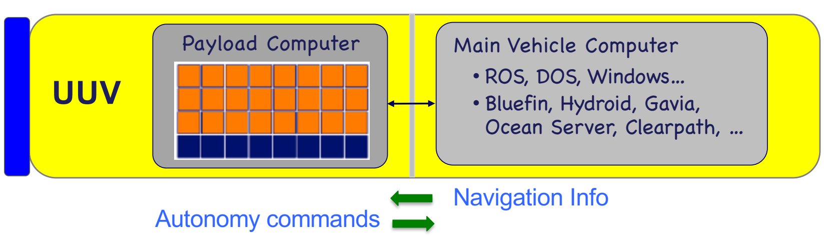
Payload UUV Autonomy



Payload computer:

Runs the autonomy and sensing system and provides a series of commands comprised of *heading, speed, depth* values.

- **Main vehicle computer:**

Implements vehicle control (converting heading and speed commands to rudder and thrust actuator commands) and provides the autonomy system with navigation information, and sensor information.

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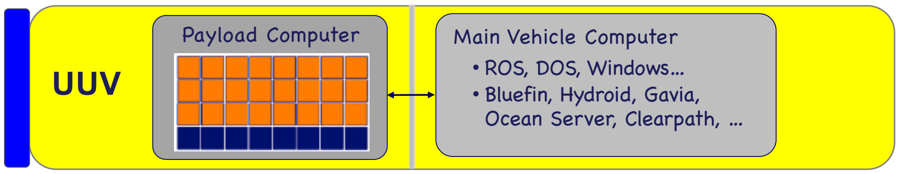
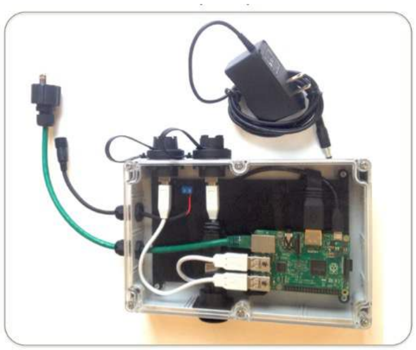
Payload UUV Autonomy





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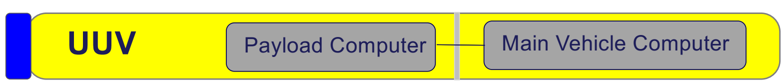
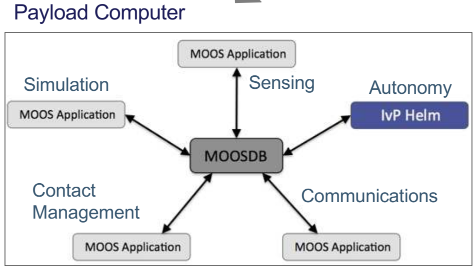
Payload UUV Autonomy



MOOS Middleware
MOOS Applications

Payload Computer



Autonomy System Middleware

De-couple Software Procurements:
- Sensing, Autonomy
- Simulation, Communications
- Mission Planning, Mission Control
- Mission Analysis

- MOOS is middleware built on the publish-subscribe architecture.
- Each MOOS application is a separate process running on the vehicle computer.
- The interface of each process is defined by the messages it publishes and the messages it subscribes for.

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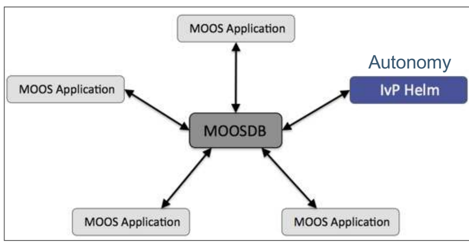
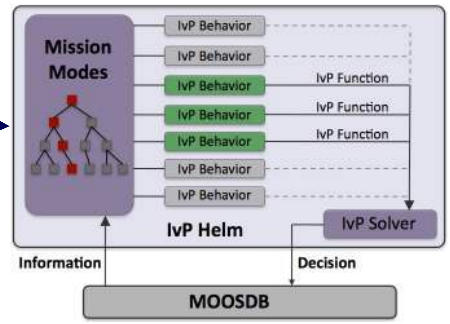
The Payload Autonomy Paradigm

- The IvP Helm is a decision-making engine based on the behavior-based architecture. It is a single MOOS application comprised of multiple specialized behaviors.
- Behaviors are turned on or off based on defined situations (states) and transitions. When multiple behaviors are active, coordination is by multi-objective optimization.
- Interval Programming (IvP) is the technique used for multi-objective optimization.

MOOS-IvP Payload Autonomy System





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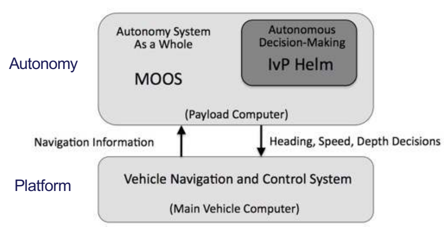
Payload UUV Autonomy

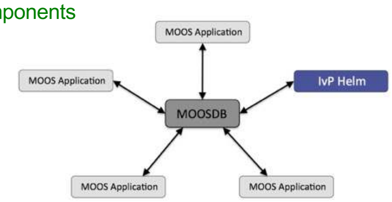
(3 Architecture Principles)

Principle #1 – Separation of Vehicle Autonomy from the Physical Platform

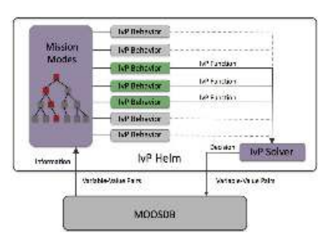


- **Choices:**
  - in vehicle type
  - in system components (MOOS Apps)
  - in autonomy components (Behaviors)
- **Diversity**
  - Anyone can build a vehicle
  - Anyone can build a MOOS app
  - Anyone can build a behavior.

Principle #2 – Separation of Autonomy System Components (MOOS Middleware)



Architecture Principle #3 – Separation into dedicated behaviors (IvP Helm)



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Behavior-Based Robotics

Commonly attributed to Rodney Brooks
A Robust Layered Control System For A Mobile Robot, IEEE Journal of Robotics and Automation, Vol. RA-2, No. 1, March 1986.

Introduced as an alternative to Good Old-Fashioned AI (GOFAI)
- Central Planner operating on a set of symbols.
- Tools:
  - Search Algorithms, combinatorics, optimization
  - Logic, predicate logic, PROLOG

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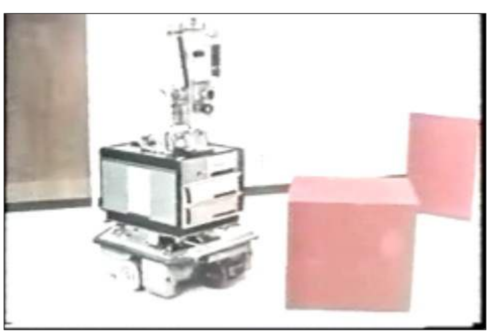
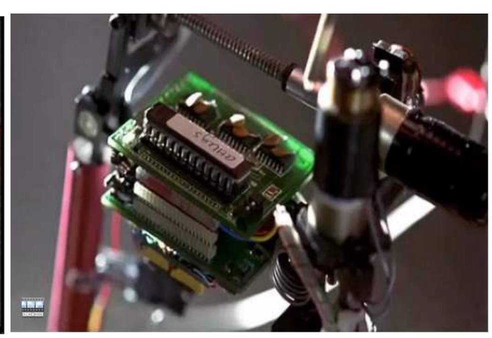
Behavior-Based Robotics

Commonly attributed to Rodney Brooks
A Robust Layered Control System For A Mobile Robot, IEEE Journal of Robotics and Automation, Vol. RA-2, No. 1, March 1986.

Good Old-Fashioned AI (GOFAI)
(Shakey the Robot)



Behavior-Based Robotics
(Genghis the Robot)



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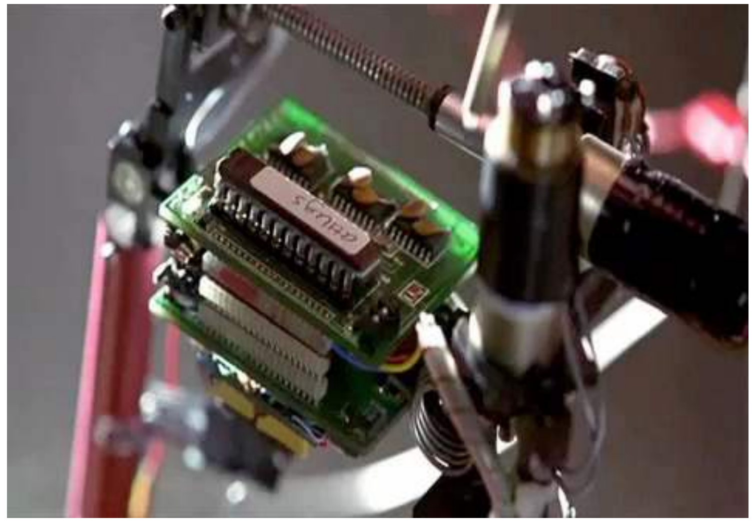
Behavior-Based Robotics

(Genghis the Robot)



Genghis was a six-legged insect-like robot that was created by roboticist Rodney Brooks at MIT around 1991. Brooks wanted to solve the problem of how to make robots intelligent and suggested that it is possible to create robots that displayed intelligence by using a "subsumption architecture" which is a type of reactive robotic architecture where a robot can react to the world around them. His paper "Intelligence With out Representation", which is still widely respected in the fields of robotics and Artificial Intelligence, further outlines his theories on this. [12]

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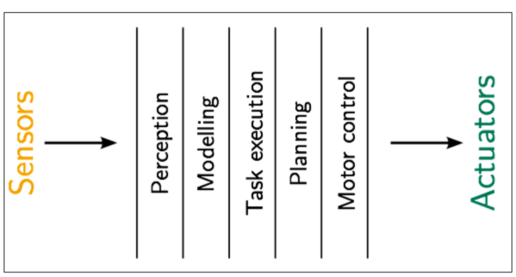
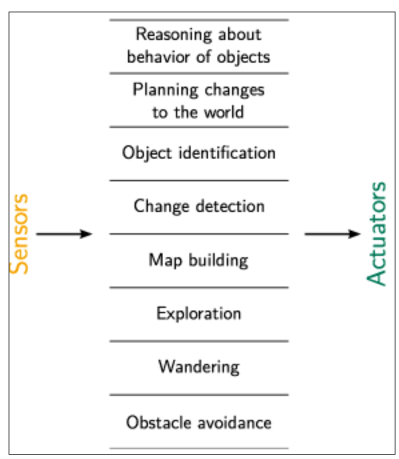
Functional vs. Behavioral Decomposition

From Brooks, *A Robust Layered Control System for a Mobile Robot, 1991.*
Figures 1,2

Functional decomposition



Behavioral decomposition



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What Did Behavior-Based Robotics Get Right and What did it Get Wrong

(In our humble opinion)

- Emergent Behavior (No planning)
  NO. Some level is fine, but in marine robotics, predictability is key.
- No State ("the world is it's own best model")
  NO. Keeping state within a behavior is powerful, no harm.
- Action Selection
  NO. Potential fields has limits. Multi-objective optimization is better.
- Evolutionary (Layered) Intelligence
  YES! This is extremely powerful in practice.

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Action Selection

Action Selection is the process of choosing a robot action based on the output of all (possibly competing) behaviors.

Simplest strategy: "Winner-take-all". The most important behavior is in complete control.

Subsumption Architecture

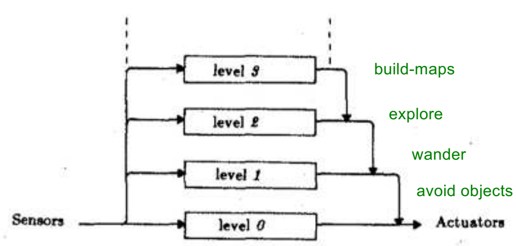

Fig. 3. Control is layered with higher level layers subsuming the roles of lower level layers when they wish to take control. The system can be partitioned at any level, and the layers below form a complete operational control system.

- From Brooks, 1986

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Action Selection

Action Selection: *one could argue that a core aspect of generally good decision-making is the ability to:*

- Find ways to accomplish multiple things simultaneously (kill two birds with one stone)
- Do the most important thing when two things are mutually exclusive, and
- Recognizing which of the above two situations you're in.

Action Selection is KEY to the goal of incremental development of intelligence.

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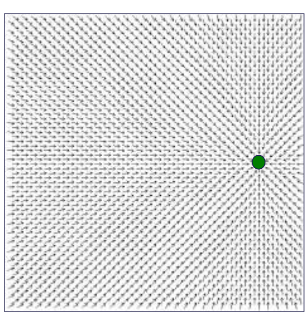
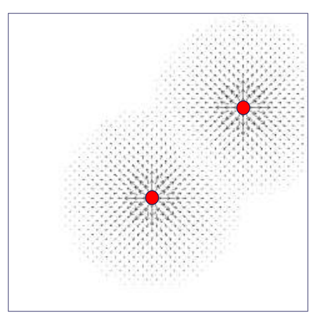
Action Selection with
Motor Schemas

Motor Schemas Multiple independent processes each generate a vector combined by weighted summation.

Based on work by Arbib, '91 (study of frogs), Arkin, '87, Khatib, '86 and others.



Go-To-Goal



Avoid-Obstacles

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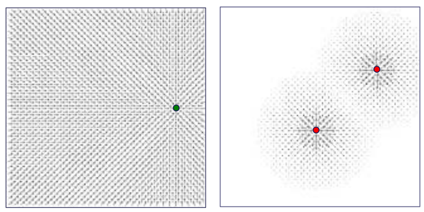
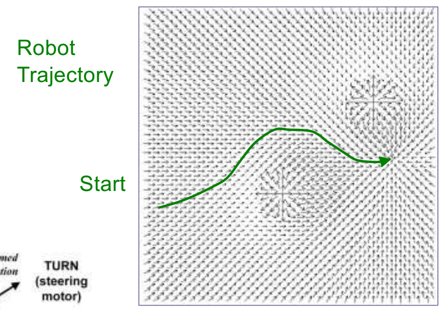
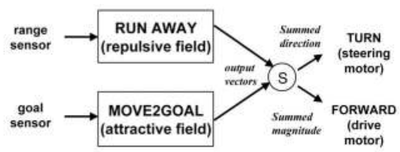
Action Selection with
Motor Schemas

Motor Schemas Multiple independent processes each generate a vector combined by weighted summation.

Based on work by Arbib, ‘91 (study of frogs), Arkin, ‘87, Khatib, ‘86 and others.





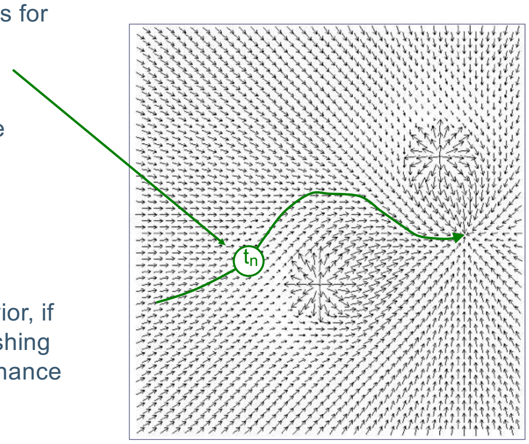


Action Selection with
Motor Schemas

At at point t_n, the robot only “feels” vectors for this point when/if it reaches that point.

A Potential Fields visualization allows us to see the vectors at all points, but the robot never computes the “field of vectors”, just the local vector.

**Key Point: From the perspective of a single behavior, if there are two equally effective vectors for accomplishing the goal, only ONE is produced. This reduces the chance for an intelligent compromise with other behaviors.



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Agent Compromise

Thought experiment: You and your friend would like to see a movie tonight.
Here are your options:

Landmark Kendall Square: Feb 19th, 2026:

1. Wuthering Heights
2. Crime 101
3. Send Help
4. Hamnet
5. No other Choice
6. Pillion
7. Paul McCartney: Man on the Run

You want to see #2, "Crime 101", and
Your friend wants to see #6, "Pillion".

How do you resolve this?
See the #4 (the average of #2 and #6?)

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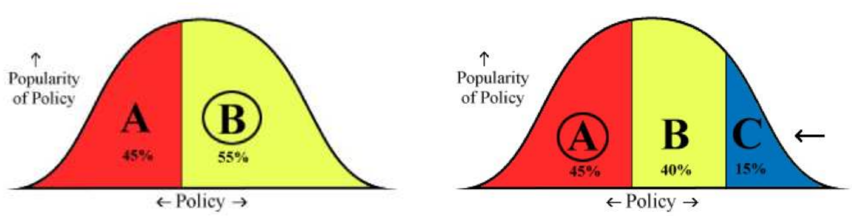
Second Choice Voting

Condorcet's Method [9]

- French mathematician and philosopher Marie Jean Antoine Nicolas Caritat, the Marquis de Condorcet.
- Each voter votes their first and second choice
- When votes are collected, instead of just counting 1st choice votes, the winners between each pair of candidates are determined.



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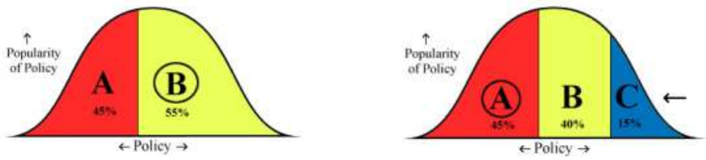
Second Choice Voting




```
1st  2nd
[X]  [ ] The candidate you really want.
[ ]  [X] The candidate you prefer if your first choice doesn’t win.
[ ]  [ ] The candidate you don’t want.
```

2000 Presidential race results New Hampshire

1. George Bush (48.07%)
2. Al Gore (46.80%)
3. Ralph Nader (3.90%)

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RANKED CHOICE VOTING

Our “choose-one” elections deprive voters of meaningful choices, create increasingly toxic campaign cycles, advance candidates who lack broad support and leave voters feeling like our voices are not heard.

https://fairvote.org

HOW RCV WORKS

Ranked choice voting (RCV) — also known as instant runoff voting (IRV) — improves fairness in elections by allowing voters to rank candidates in order of preference.

RCV is straightforward:
Voters have the option to rank candidates in order of preference: first, second, third and so forth. Votes that do not help voters’ top choices win count for their next choice.

RCV eliminates problems like vote-splitting, so-called “spoiler” candidates and unrepresentative outcomes that can arise when more than two candidates run for a single position.

https://www.youtube.com/watch?v=gq7N2hmX9FI&t=3s

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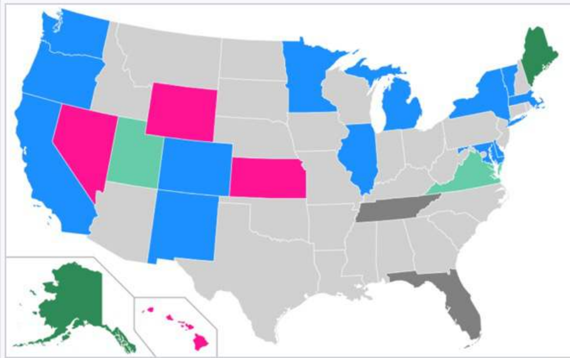
RANKED CHOICE VOTING



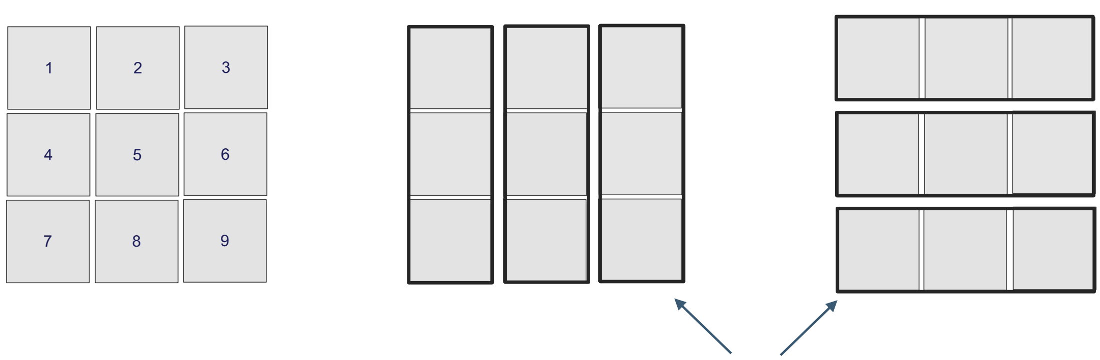
Ranked-choice voting the US by state

- State-wide use
- Local option for municipalities to opt-in
- Local elections in some jurisdictions
- Use in presidential primaries
- RCV banned state-wide

GERRYMANDERING

A Simple Illustrative example:
- Nine voters
- Three congressional districts, each with three voters

Districting: Determining which voters go win which district.
- Controlled by a committee with comprised of the party in power
- There are no universally clear-cut rules on how the districts are drawn.



Two viable options

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A Simple Illustrative example:
- Nine voters
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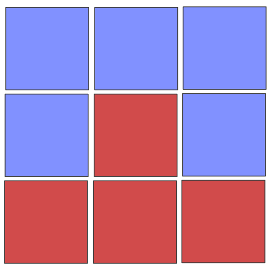
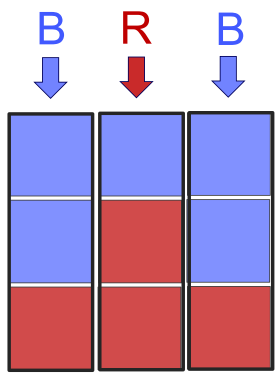
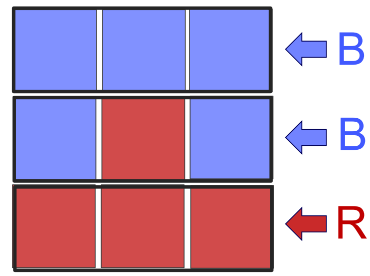


5 Blue voters
4 Red Voters





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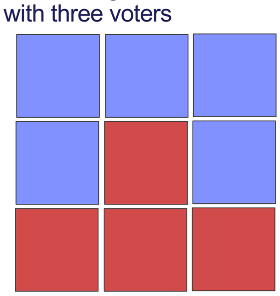
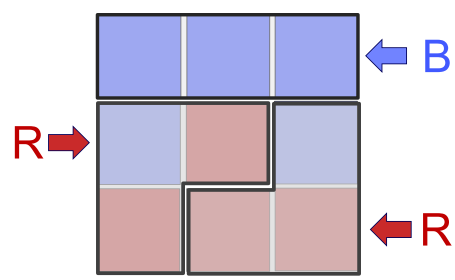
A Simple Illustrative example:
- Nine voters
- Three congressional districts, each with three voters



With today's profiling technology, it is quite possible to know which voters live where.

Then if you control the drawing of district lines…



5 Blue voters

4 Red Voters

5 Blue voters → One congressional seat
4 Red Voters → Two congressional seats!

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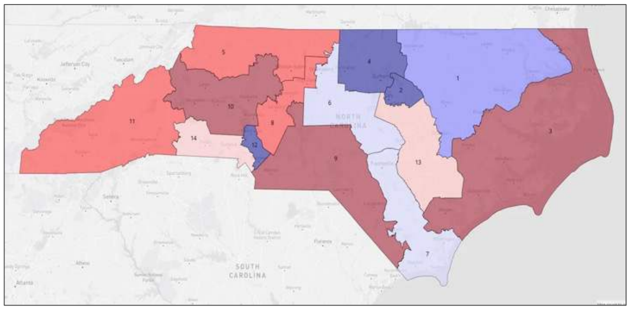
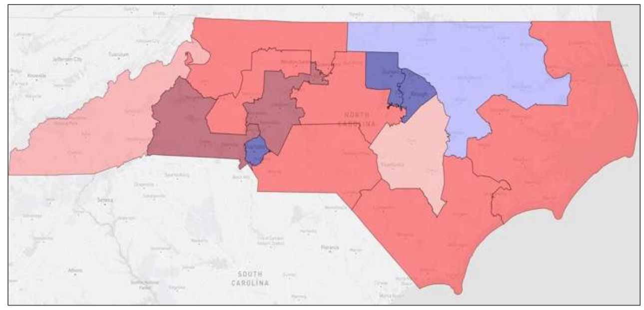
Un-rigging North Carolina elections? 5 things to know about the latest in NC redistricting (Feb 23, 2022)

https://www.fayobserver.com/story/news/2022/02/21/nc-elections-2022-redistricting-maps-fair-vote-gerrymandering-congress-ncga/6804181001/



8-6 Split



10-4 Split

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Action Selection

Good Decision-making in a ***democratic government*** depends on informed consensus among its citizens – one vote per person equally.

Good Decision-making in a ***behavior-based AI system*** depends on consensus between component behaviors. Behaviors may be unequal in weight.

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Action Selection with
Behavior Voting

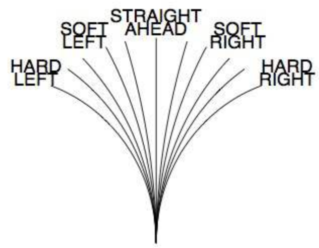

Figure 7: Curvature-based turn command space

An example decision space

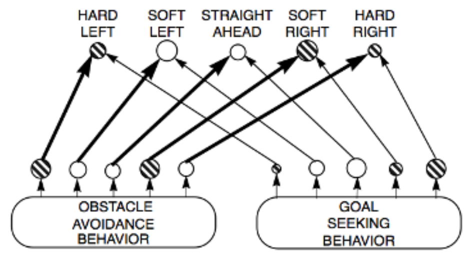

Figure 8: Behavior voting in DAMN

- From Rosenblatt, 1997

- Each decision receives full consideration by each behavior, and by the solver.
- Problem: The decision space is rarely one-dimensional. Coupled decision spaces grow exponentially.

Action Selection
with Multi-Objective Optimization

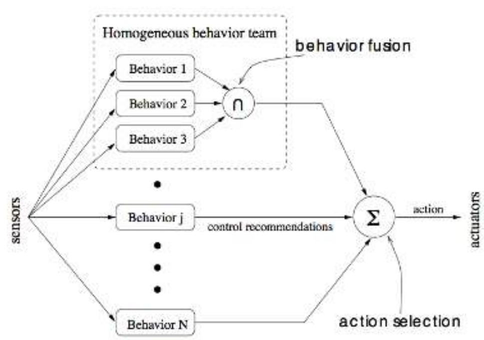

Figure 1.4: *Schematic overview of the action selection process, the behavior fusion process and their relationship.* $\cap$ *symbolizes the fusion of homogeneous behaviors and* Σ *symbolizes the action selection process.*

- From Pirjanian, 1998

- Pirjanian recognized that "voting" is a form of multi-objective optimization, and
- Voting needs to be done in a high-dimensional coupled decision space.

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Action Selection
with Multi-Objective Optimization

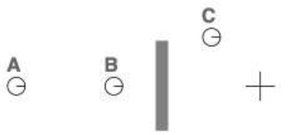

Figure 3.6: *Test scenario.* ⊖ *represents the robot and* + *represents the target.*

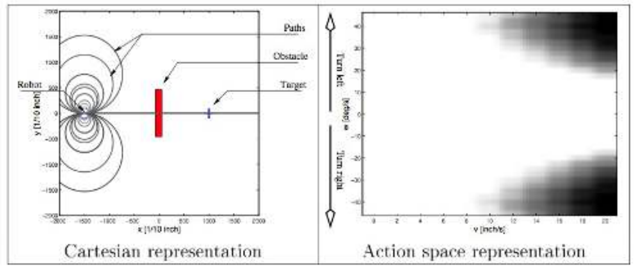

Figure 3.12: *Example plots of the representations used for visualizing the process of action selection. On the left, the robot and the recommended paths are depicted in Cartesian coordinates. The figure on the right is a plot of the action space, i.e., each cell in the figure corresponds to an action given by* (v, ω)*. The color of the cells indicate the corresponding actions appropriateness.*

Pirjanian recognized that "voting"
Is a form of multi-objective
optimization, and that this needs to be
done in a high-dimensional coupled
decision space.

- From Pirjanian, 1998

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Action Selection
with Multi-Objective Optimization

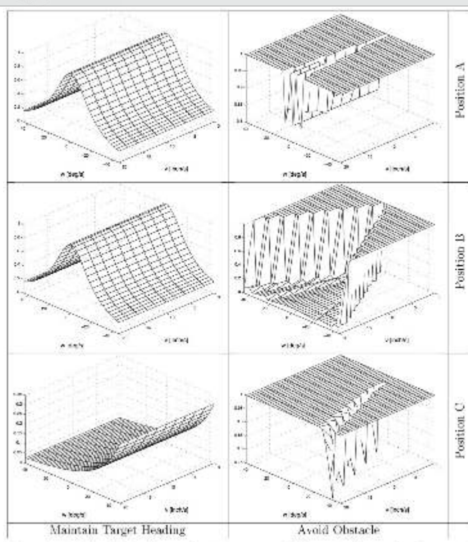

Figure 3.13: *Plot of the objective functions at specified locations depicted in figure 3.6*

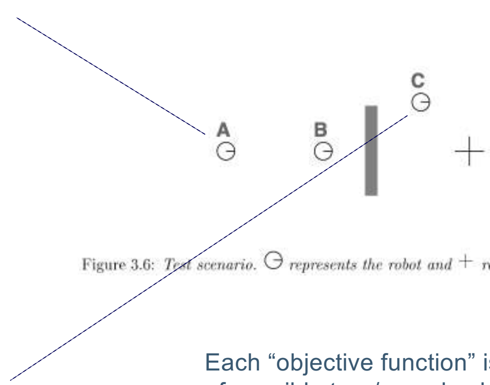

Figure 3.6: *Test scenario.* ⊖ *represents the robot and* + *represents the target.*

Each "objective function" is a full explicit listing of possible turn/speed values.

Optimization is done by brute force.

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Action Selection with Interval Programming

Behavior 1 → $f_1(x_1, x_2, \ldots, x_n)$
Behavior 2 → $f_2(x_1, x_2, \ldots, x_n)$
Behavior 3 → $f_3(x_1, x_2, \ldots, x_n)$

Objective Functions

$$\vec{x}^* = \underset{\vec{x}}{\operatorname{argmax}} \sum_{i=0}^{k-1} w_i f_i(\vec{x})$$

Solver

→ Action

- The solution is the single decision that maximizes the weighted sum of all utility functions.

Key features of Interval Programming:

- All objective functions are piecewise linearly defined.
- No restrictions on function form (nonlinear, non-convex, discontinuous).
- Solver produces globally optimal solution guaranteed.
- "Interval Programming (IvP)" refers to both the representation scheme for objective functions, and the solution algorithm exploiting the function form.

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Action Selection with Interval Programming

Behavior 1 → $f_1(x_1, x_2, \ldots, x_n)$
Behavior 2 → $f_2(x_1, x_2, \ldots, x_n)$
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Objective Functions

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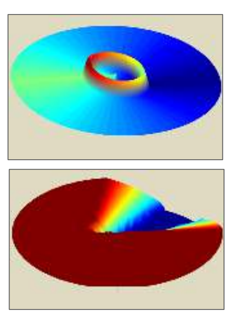
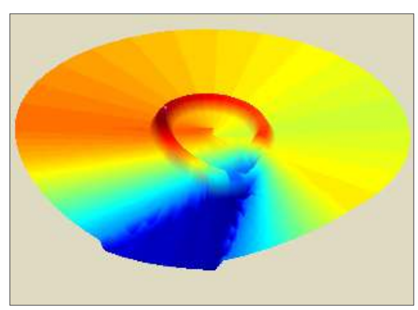
Solver

→ Action





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Action Selection with Interval Programming

Behavior 1 → $f_1(x_1, x_2, \ldots, x_n)$
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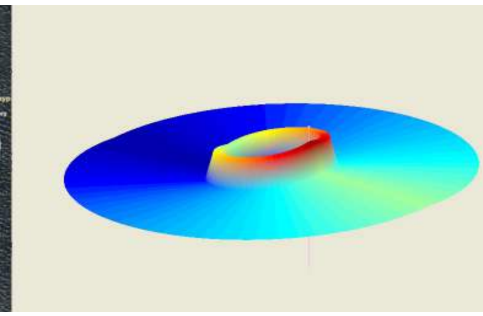
Objective Functions

$$\vec{x}^* = \underset{\vec{x}}{\operatorname{argmax}} \sum_{i=0}^{k-1} w_i f_i(\vec{x})$$

Solver

Action



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Action Selection

Action Selection Methods

- No-compromise (subsumption) — Brooks, 1985
- Compromise
  - Single Fusion (potential fields) — Khatib, 1986; Arkin, 1987
  - Multi-Fusion
    - Single-Dimension (behavior voting) — Rosenblatt, 1996
    - High-Dimension
      - Explicit-Evaluation (multi-objective optimization) — Pirjanian, 1998
      - Implicit-Evaluation (Interval Programming) — Benjamin, 2002

Action Selection Evolution?

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Action Selection – in a Nutshell

Action Selection: one could argue that a core aspect of generally good decision-making is the ability to:

- Find ways to accomplish multiple things simultaneously (kill two birds with one stone)
- Do the most important thing when two things are mutually exclusive, and
- Recognizing which of the above to two situations you're in.

Action Selection is KEY to the goal of incremental development of intelligence.

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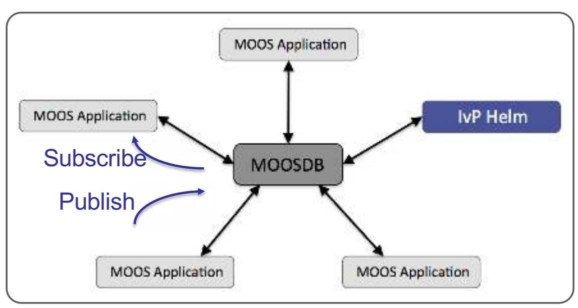
The IvP Helm

- The IvP Helm is a MOOS App, sharing many common features of all MOOS Apps
- It runs as pHelmIvP
- It is a behavior-based architecture.

- Other MOOS Applications may work in conjunction with the helm, performing sensor-processing, planning, communications.
- The degree to which one seeks a "hybrid" architecture (deliberative vs. reactive) is determined by the user.



A MOOS Community

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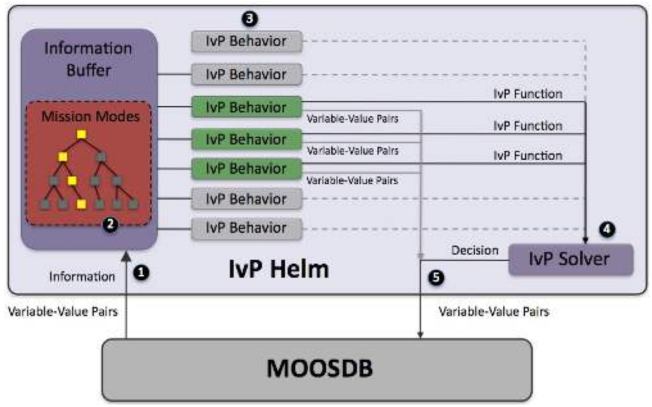
Interval Programming and the IvP Helm

1. Mail is read in the MOOS OnNewMail() function and applied to a local buffer.
2. The helm mode is determined and set of running behaviors determined.
3. Behaviors do their thing – posting MOOS variables and an IvP function.
4. Competing behaviors are resolved with the IvP solver.
5. The Helm decision and any behavior postings are published to the MOOSDB.



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Interval Programming and the IvP Helm

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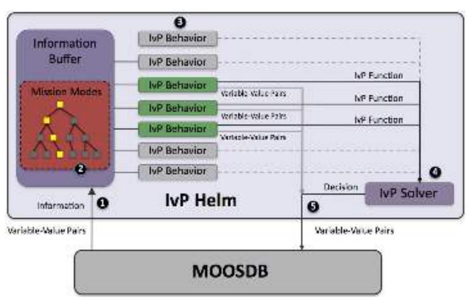

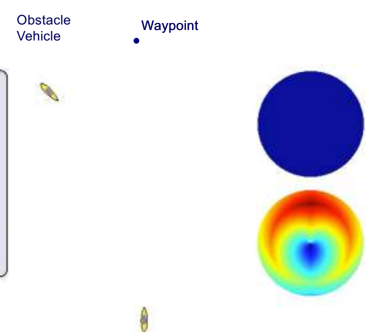

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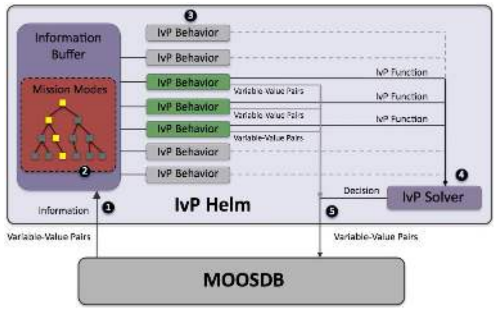
IvP Helm Configuration



Helm configuration file structure:

file.bhv

- Variable Initializations
- Hierarchical Mode Declarations
- Behavior Configurations

```
Behavior = <behavior_name>
{
  parameter = value
  . . .
  parameter = value
}
```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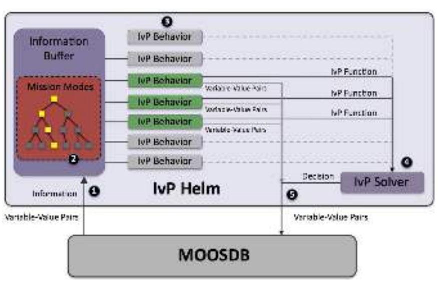
IvP Helm Configuration



file.bhv

- Variable Initializations
- Hierarchical Mode Declarations
- Behavior Configurations

```
Behavior = BHV_Loiter
{
  name      = loiter
  priority  = 100
  condition = (DEPLOY=true) and (REGION=A)

         speed = 1.8
     clockwise = false
        radius = 4.0
     nm_radius = 25.0
       polygon = format=radial, x=0, y=-75,
                 radius=40, pts=8
}
```

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Simple Example: “Double Loiter”

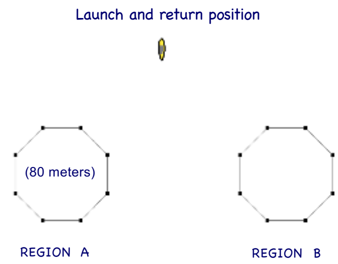
Mission Synopsis:

Upon receiving a deploy command, transit to and loiter at region A for a fixed duration and then to region B. Periodically switch between regions until recalled home.

```
Behavior = BHV_Loiter
{
  name      = loiter_a
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=0,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Loiter
{
  name      = loiter_b
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=160,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Return
{
  name      = return
  condition = (DEPLOY=true) and (RETURN=true)

  speed = 1.8
  radius = 4.0
  point = 80,40
}
```



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Simple Example: “Double Loiter”

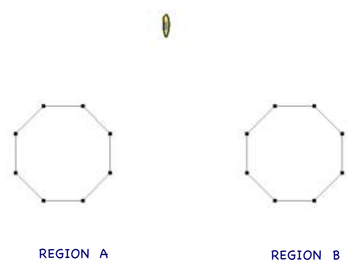
Mission Synopsis:

Upon receiving a deploy command, transit to and loiter at region A for a fixed duration and then to region B. Periodically switch between regions until recalled home.

```
Behavior = BHV_Loiter
{
  name      = loiter_a
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=0,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Loiter
{
  name      = loiter_b
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=160,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Return
{
  name      = return
  condition = (DEPLOY=true) and (RETURN=true)

  speed = 1.8
  radius = 4.0
  point = 80,40
}
```



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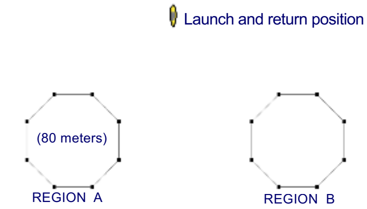
Simple Example: "Double Loiter"

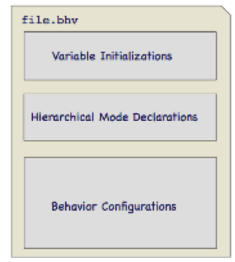
```
Behavior = BHV_Loiter
{
  name      = loiter_a
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=0,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Loiter
{
  name      = loiter_b
  condition = (DEPLOY=true) and (REGION=A)

  speed = 1.8
  radius = 4.0
  polygon = format=radial,x=160,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Return
{
  name       = return
  condition = (DEPLOY=true) and (RETURN=true)

  speed = 1.8
  radius = 4.0
  point = 80,40
}
```




```
Initialize  DEPLOY = false
Initialize  RETURN = false
Initialize  REGION = A
```



Mission Synopsis:

Upon receiving a deploy command, transit to and loiter at region A for a fixed duration and then to region B. Periodically switch between regions until recalled home.

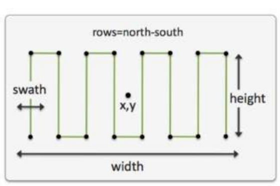
Waypoint Behavior

Points may be specified explicitly, e.g. the alpha mission:

```
points = 60,-40 : 60,-160 : 150,-160 :
         180,-100 : 150,-40
```

Points may be specified by pattern description:

```
points = format=lawnmower, x=115, y=-100,
height=120, width=100, lane_width=12,
rows=north-south, startx=0, starty=0, degs=0
```



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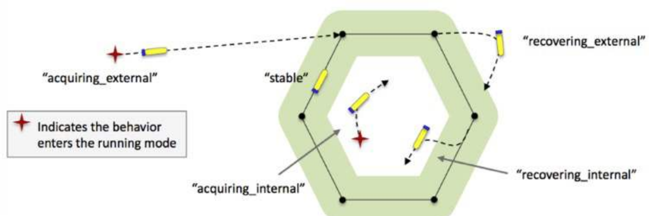
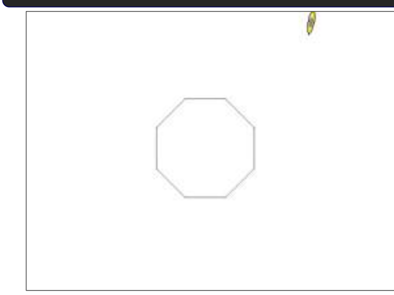
Loiter Behavior

Points specified by may be convex polygon

```
polygon = radial::x=75,y=-75,radius=50,pts=12
```

Loiter entry and recover is robust to disruptions





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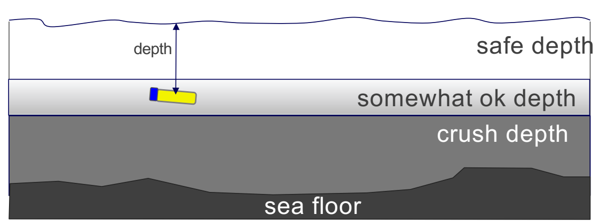
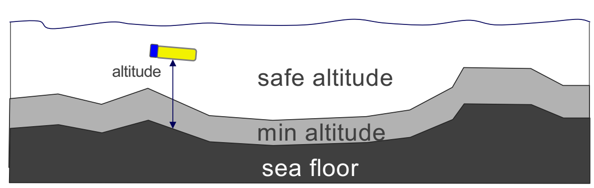
Min Altitude / Max Depth Behaviors

- **MaxDepth behavior** will disallow a depth command below critical depth.
- Near-critical depths are ranked poorly but could be allowed if other behaviors need to go deep.



- **MinAltitude behavior** will disallow depths with low altitude to the sea floor
- Near-critical altitudes are ranked poorly but could be allowed if other behaviors need to go deep.



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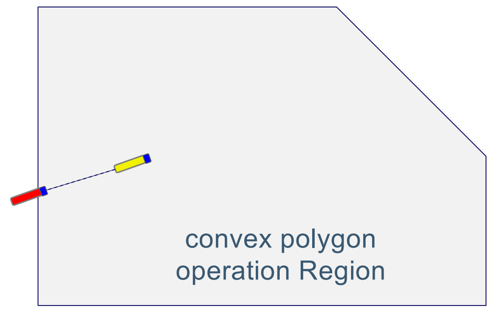
OpRegion Behavior

- **OpRegion behavior** has a convex polygon region.
- If the vehicle goes outside this region, a vehicle all-stop is issued.
- Status posts are made indicating range/time to exiting the region. To allow corrective actions to be initiated



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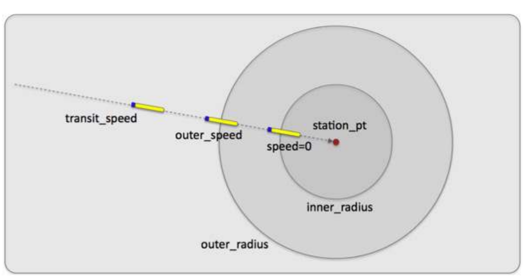
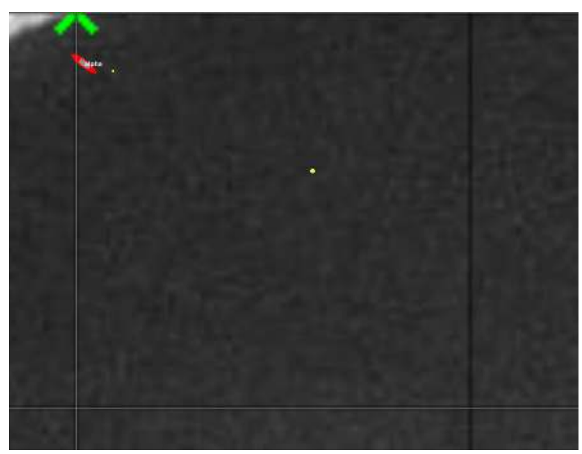
StationKeep Behavior

- **StationKeep behavior** keeps a vehicle on station defined by a point
- It can be set to continuously adjust
- It can be set to periodically adjust while drifting during inactivity





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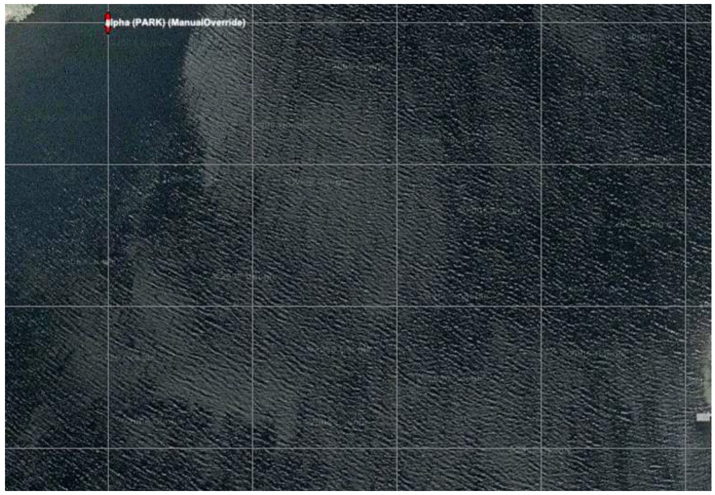
Today's Lab Preview

- We will construct several example missions, each building on the prior mission.
- The Alpha Return Mission

Assignment #2:
Modified Alpha mission with vehicle returning on user command.



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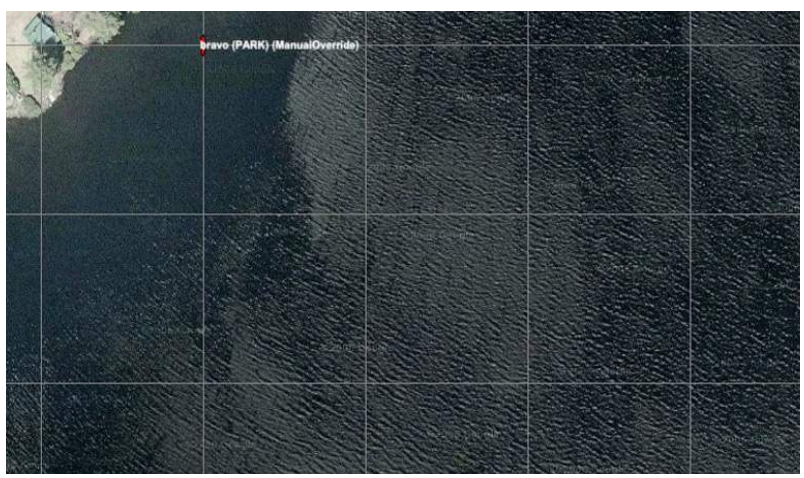
Today's Lab

- We will construct several example missions, each building on the prior mission.
- The Bravo Loiter Double Mission

Assignment #4:
Double Loiter automatically switching modes



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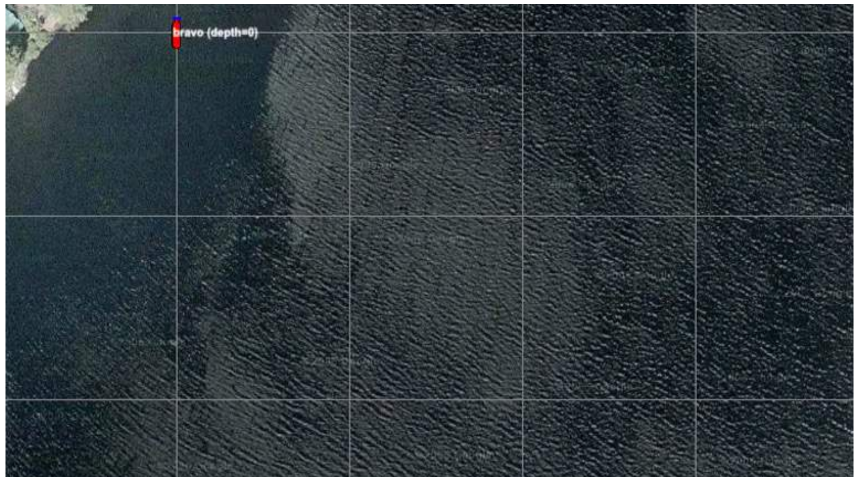
Today's Lab

We will construct several example missions, each building on the prior mission.
The Bravo UUV Surface Mission

Assignment #6:
Double Loiter with depth and periodic surfacing



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END

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