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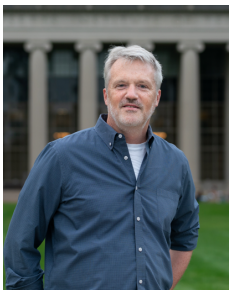
An Introduction to Robot Autonomy

ROBOTICS RESEARCH CENTER (RRC)

with
MOOS-IvP
and
Aquaticus

Lecture 1: Overview



Michael Benjamin, PhD
MIT Dept of Mechanical Eng.
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MOOS-IvP Supported by ONR Code 311 since 2000

Prof. Michael "Misha" Novitzky
United States Military Academy
michael.novitzky@westpoint.edu

Aquaticus Supported by ONR, DARPA, Battelle and the Army Research Lab

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MOOS-IvP and Aquaticus

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MOOS-IvP

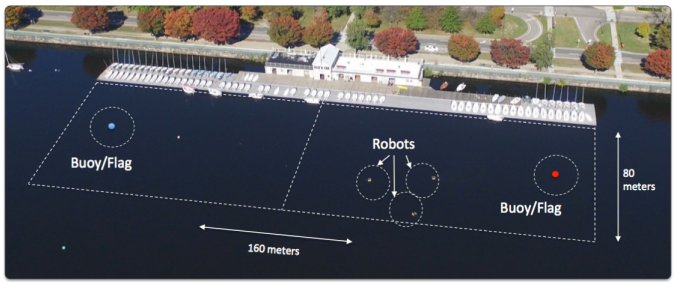
www.moos-ivp.org

- MOOS robot middleware
- IvP Autonomy architecture
- Open source since 2006
- On dozens of platform types around the world

Aquaticus

www.aquaticus.org

- An adversarial competition
- Based on capture-the-flag
- Played on the water
- Software infrastructure MOOS-IvP
- Started at MIT, now at West Point.



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Robot Autonomy

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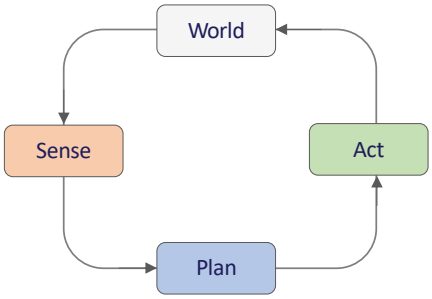
- Where am I in the world?
- What objects exist and where are they?
- Where are my teammates?
- Where are my adversaries?
- What is the game/mission state?



- What signal should be sent to the actuator(s) given the latest decision?

- What do I do next?
- What messages do I send to teammates?
- What messages do I send to command control?

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Robot Autonomy

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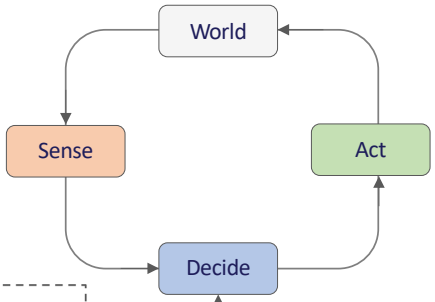

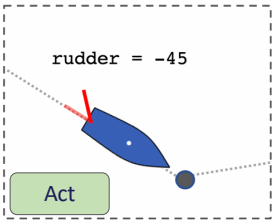

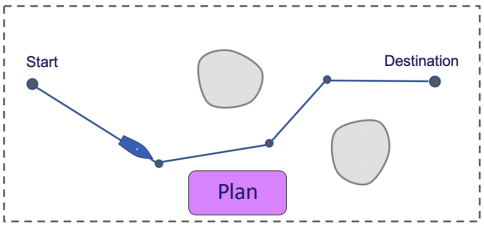

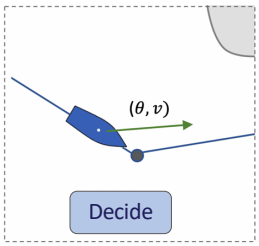

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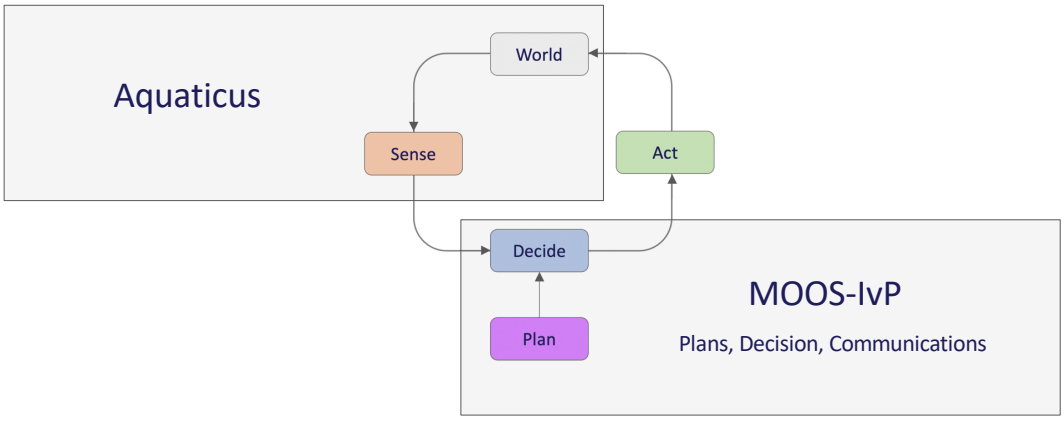
Aquaticus Research Focus: Plans, Decisions, Communications



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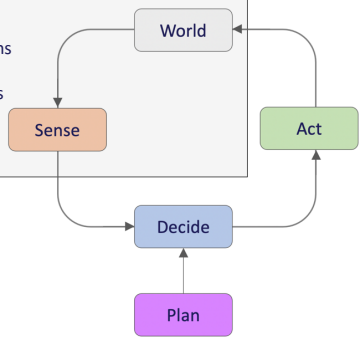
Aquaticus Research Focus: Plans, Decisions, Communications

Aquaticus

- Limited world: game state, vehicle positions
- Simplified sensing:
  a) All vehicles know all vehicle positions
  b) Tactical game state Sensors



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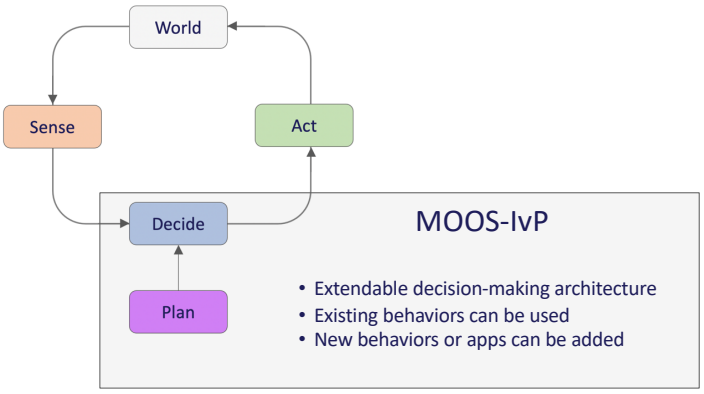
Aquaticus Research Focus: Plans, Decisions, Communications



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Aquaticus

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Aquaticus Human-Robot Cooperative Teaming Test-bed

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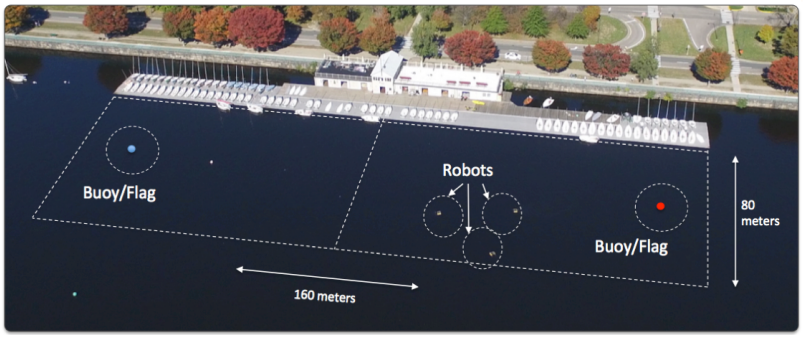
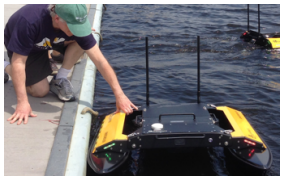
DARPA ONR





- Mixed Human-robot teaming with humans in field with robot teammates.
- Unique factor: full in-field integration of human teammates. Multiple communication modes.
- Field is ~160x80m on Charles River at MIT.
- Choice of robot autonomy configurations, modes, strategies, contingencies, protocols must consider what is most useful and digestible to humans
- Humans are in motorized kayaks with voice-to-text for comms to robots.

- Funded by DARPA TTO through ONR. Seedling.
- Full competitions (4 on 4) during summer 2018.
- Operated in conjunction with Marine Autonomy Summer High School Program (Year 3, 2018)
- Human-Use Approval (MIT, DoD) March 2017.
- Goals, operating environment, team structure may be changed mid-competition, per requests of model developers.

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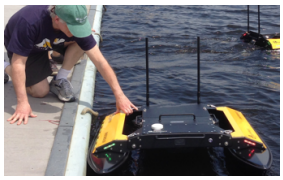

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Sense-Plan-Act | Aquaticus Overview | Autonomy Architectures | Information Flow MOOS Intro | MOOS-IvP | Payload Autonomy | Lab 1 Overview

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Aquaticus Playing Field

Competition based on Capture the Flag

- Flags are anchored buoys
- "capturing" of flags is virtual. Must be within flag zone.
- Field boundaries are virtual with penalties for going out of bounds

Location: Charles River at MIT

Dimensions: 160x80m

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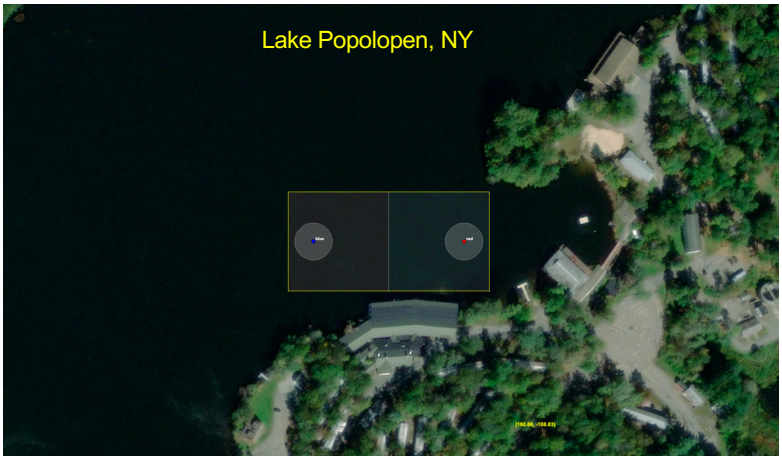
Moving to West Point NY

- Flags are anchored buoys
- "capturing" of flags is virtual. Must be within flag zone.
- Field boundaries are virtual with penalties for going out of bounds



Location: Lake Popolopen, NY

Dimensions: 160x80m

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Aquaticus Playing Field

Competition based on Capture the Flag

- Flags are anchored buoys
- "capturing" of flags is virtual. Must be within flag zone.
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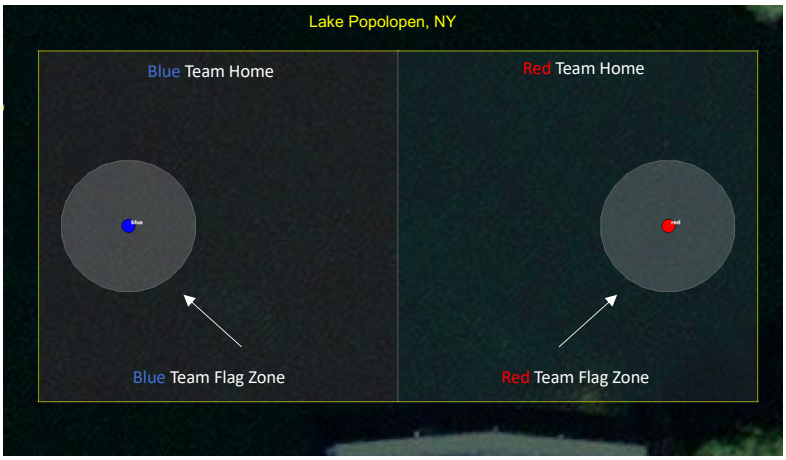

Location:
Lake Popolopen, NY

Dimensions:
160x80m

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Aquaticus Software and Missions

To run the Aquaticus simulation, two code bases are required:

moos-ivp-aquaticus	Both have public URLs for downloading
moos-ivp	

Our first lab will ensure both codebases are on your system, and simple test missions will run

moos-ivp-aquaticus	The Aquaticus alpha mission The Aquaticus bravo mission
moos-ivp	The MOOS IvP alpha mission

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Autonomy Architecture
MOOS-IvP

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Architecture Perspectives

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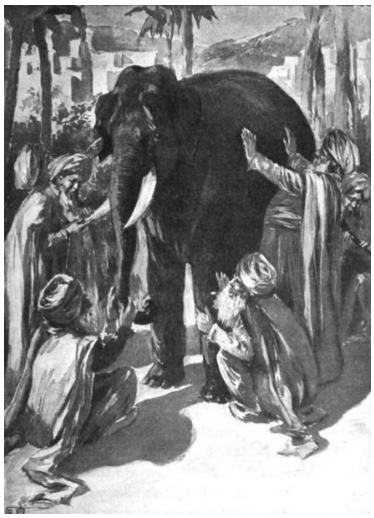
The Blind Men and the Elephant:

A group of blind men who have never come across an elephant before and who learn and conceptualize what the elephant is like by touching it. Each blind man feels a different part of the elephant's body, but only one part, such as the side or the tusk.

The first person, whose hand landed on the trunk, said, "This being is like a thick snake". For another one whose hand reached its ear, it seemed like a kind of fan. As for another person, whose hand was upon its leg, said, the elephant is a pillar like a tree-trunk. The blind man who placed his hand upon its side said the elephant, "is a wall". Another who felt its tail, described it as a rope. The last felt its tusk, stating the elephant is that which is hard, smooth and like a spear.

The moral of the parable is that humans have a tendency to claim absolute truth based on their limited, subjective experience as they ignore other people's limited, subjective experiences which may be equally true. [1]



MOOS-IvP will be described by several architecture descriptions. Each highlights a different key perspective, while over-simplifying other perspectives. They are all "correct", and collectively will provide a suitable description of MOOS-IvP.

[1] https://en.wikipedia.org/wiki/Blind_men_and_an_elephant

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Sense-Plan-Act

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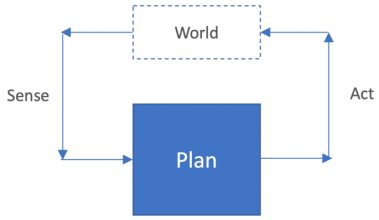
- This is the simplest architecture description
- For more complex architectures to follow, hopefully we will still be able to step back and still see the "sense-plan-act"



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Planning vs Decision-Making

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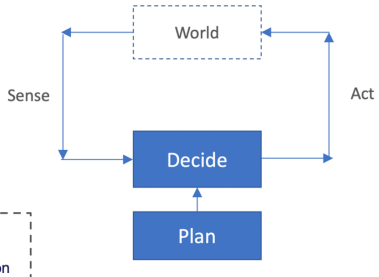
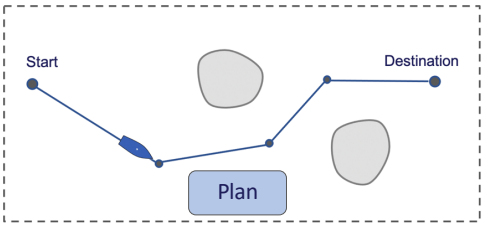
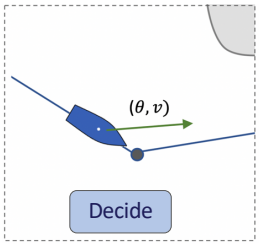
The terms planning and decision-making are quite distinct, at least in our vocabulary.

- In some mission, the plan may be set once, before the vehicle even launches.
- (Re)-Planning may also occur periodically during a mission as substantial new info is obtained.
- A new plan may also be communicated to the vehicle mid-mission.



- Decision-making occurs continuously
- Decision-making may be executing a plan
- This is the primary focus of the IvP Helm





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Mission-Planning and Comms

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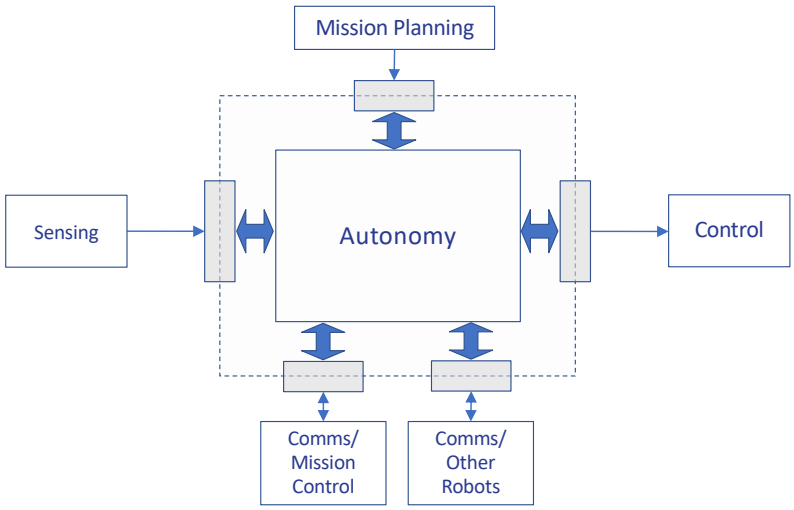

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Sensing Components

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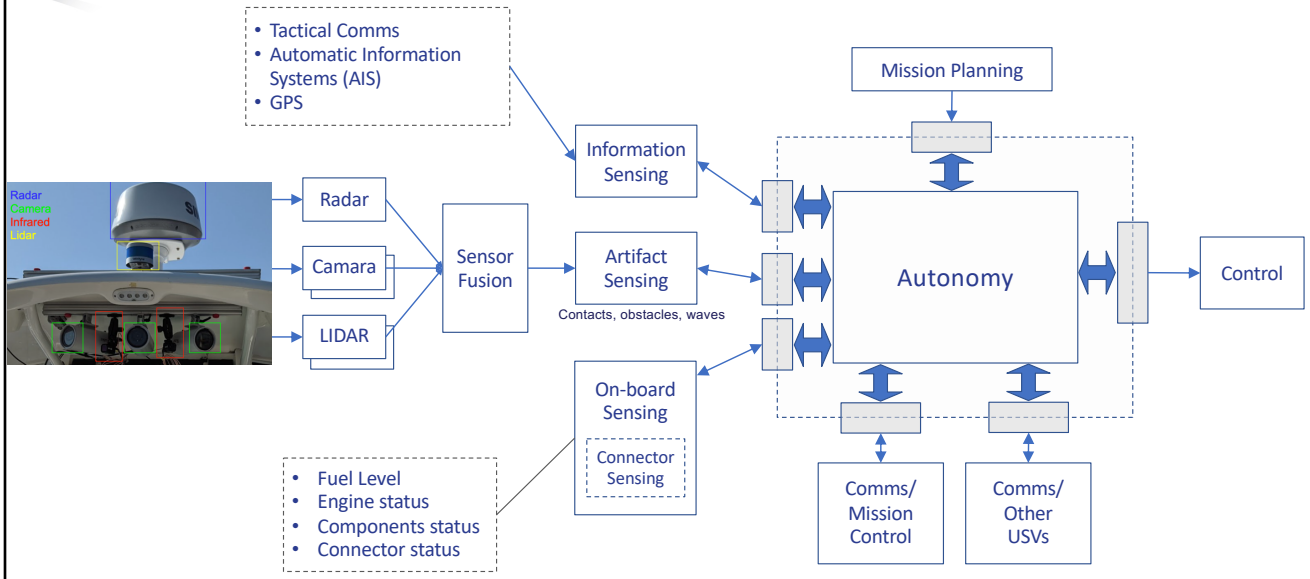

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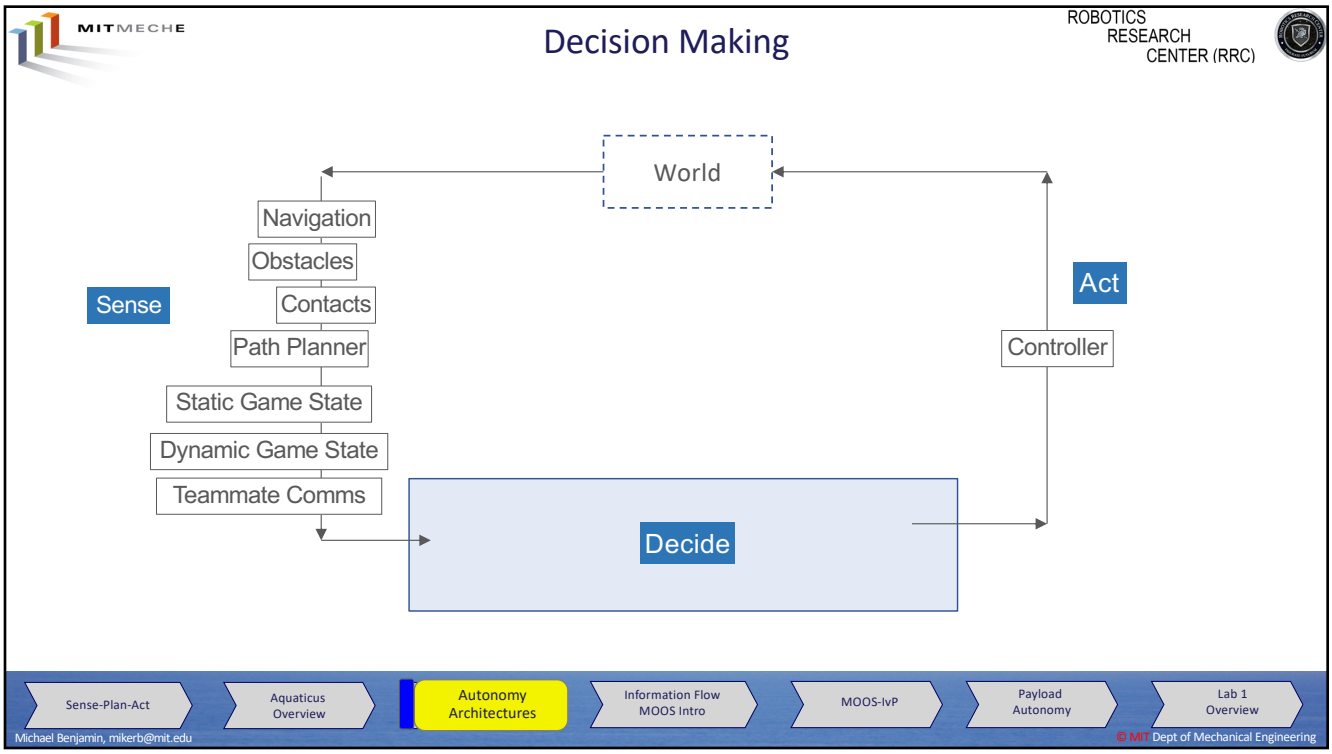
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Decision Making
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World
Navigation
Obstacles
Contacts
Path Planner
Static Game State
Dynamic Game State
Teammate Comms
Sense
Act
Controller
Decide
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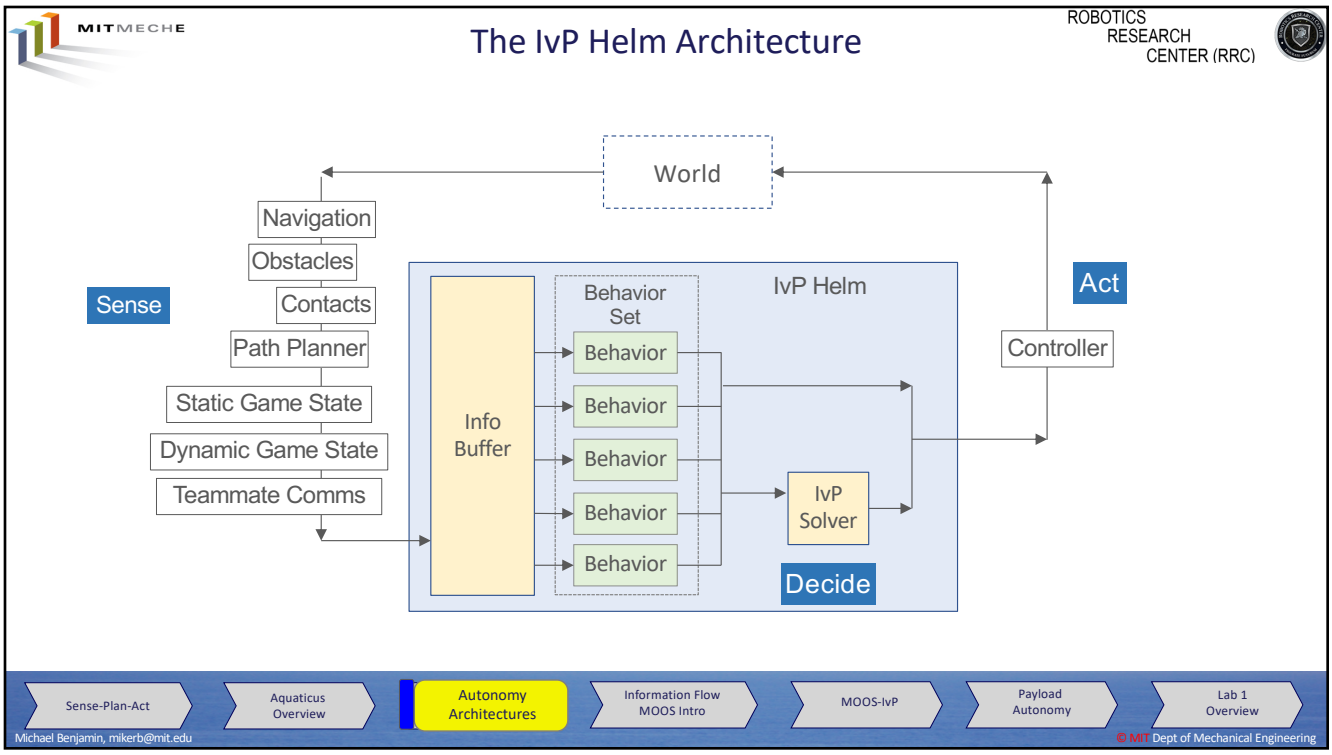
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The IvP Helm Architecture
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World
Navigation
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Static Game State
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Teammate Comms
Sense
Act
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Info Buffer
Behavior Set
IvP Helm
Behavior
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Information Flow

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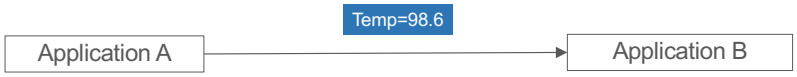
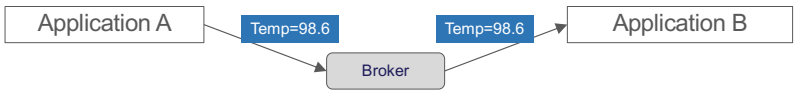
- The various blocks in our architecture need to share information.



- We want this interface to be as generic as possible
- Ideally Application A and B are designed without ever considering each other



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Information Flow

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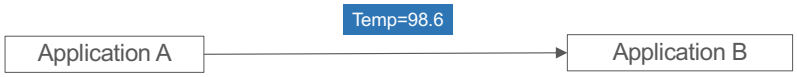
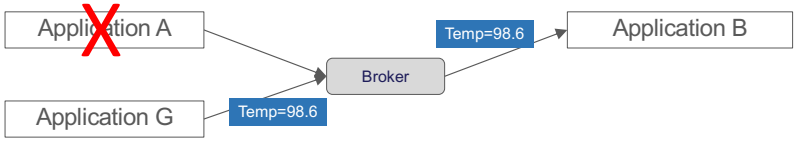


- We want this interface to be as generic as possible
- Ideally Application A and B are designed without ever considering each other

A better version of App A has been developed. Easy to replace.



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Information Flow

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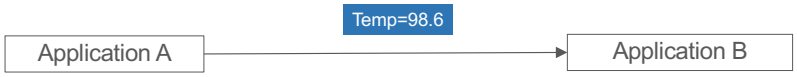
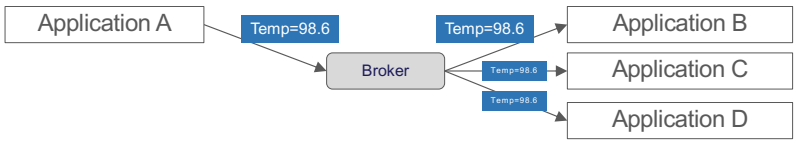


- We want this interface to be as generic as possible
- Ideally Application A and B are designed without ever considering each other

Additional apps may want to consume the same information for different purposes.
Easy to add.



(Original purpose)

Some other reason, e.g., visualization

Some other reason, e.g., analysis

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A MOOS Community

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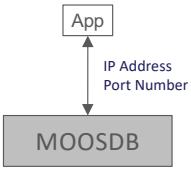
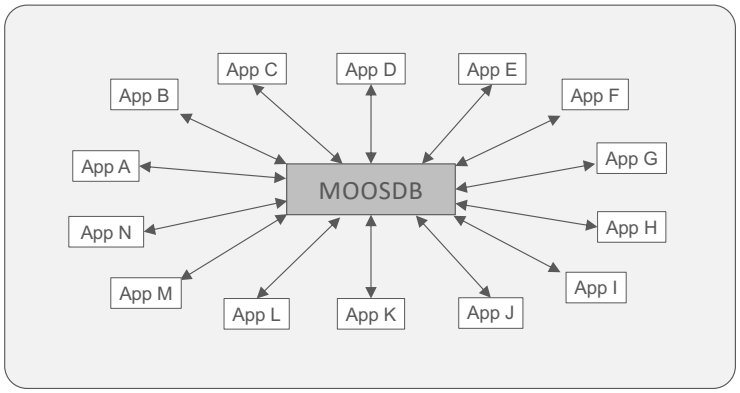
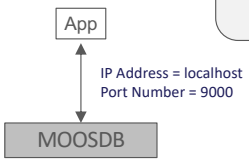
The MOOSDB is a server, providing a service over a configured port, on a particular IP address (not unlike a web server).

An App connects by passing it the IP address and port number where it can expect to find the MOOSDB





In most situations, the App and MOOSDB are running on the same machine (localhost), and the MOOSDB is using the default port number of 9000.



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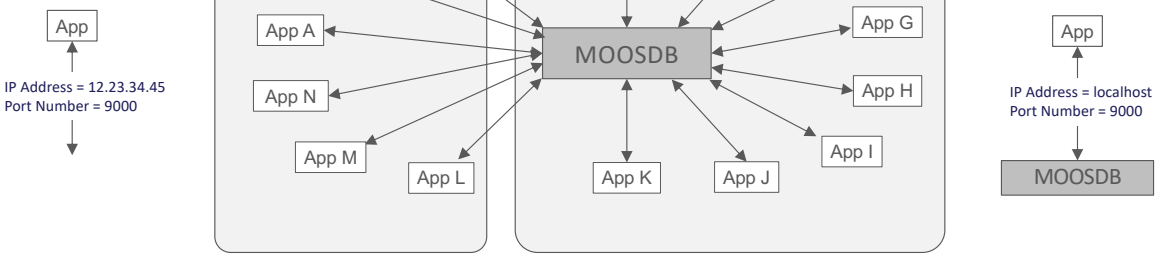
A Distributed MOOS Community

A single MOOS community (having a single MOOSDB), may be distributed over the network. Apps running on the remote machine simply need to know the IP address of the machine running the MOOSDB.

The two machines could be anywhere world-wide, but are typically two machines on the same robotic platform, as a way of bringing more computational power.



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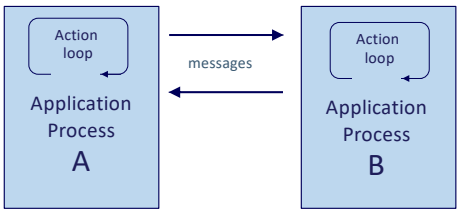
MOOS Does Two Main Things

1. It enables distinct applications to communicate
2. It enables users to control the frequency of each application's action loop



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A MOOS Community

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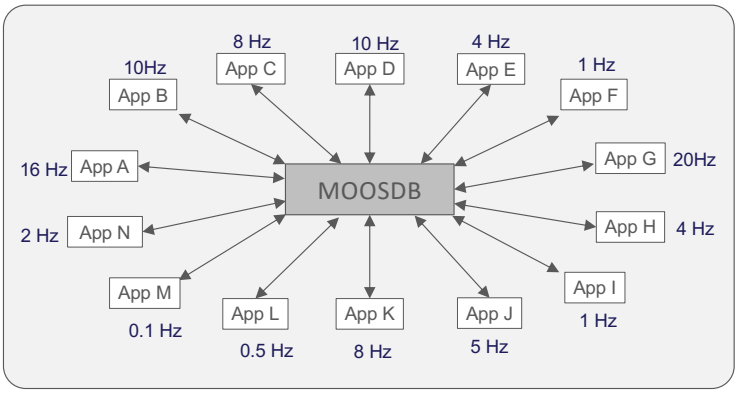
- The application frequency is set upon, at mission planning time
- If the CPU cannot meet the requested frequency, it will do the best it can
- The user can implement "back-off" within the app itself if desired.



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The Beauty of Separate Processes

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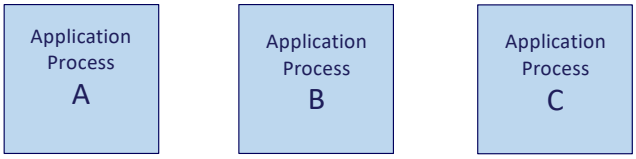

On Unix based systems, each process:

- Has a unique Process ID (PID)
- Uses a chunk of computer memory *separate* from all other processes

Advantages:

- A crash in one process will not affect another process
- The OS automatically distributes processes over system CPU cores

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MOOSDB is a Process for Communication

- It has its own PID and memory space like any other process
- It maintains a mapping for Variable Names → Values

MOOSDB

FRUIT	apples
ANGLE	135
SPEED	2.8
NAME	alpha
WIDTH	86
HOURS	23

Only the most recent value is retained

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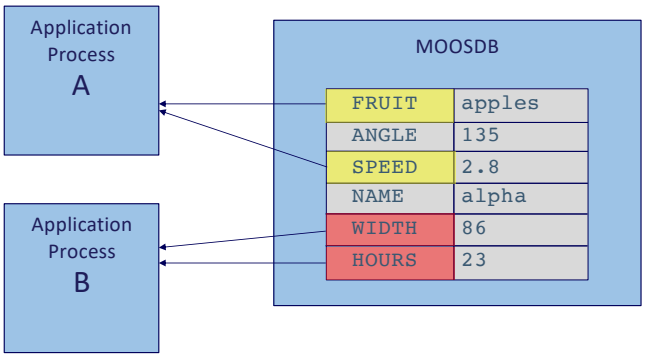
MOOS Apps Subscribe to the MOOSDB

- An App may register (subscribe for) for any variable
- An App may register any time, but typically during startup
- Multiple apps may register for the same variable



When an App first connects, it gets mail for each registered variable.

(if the variable has ever been written to)

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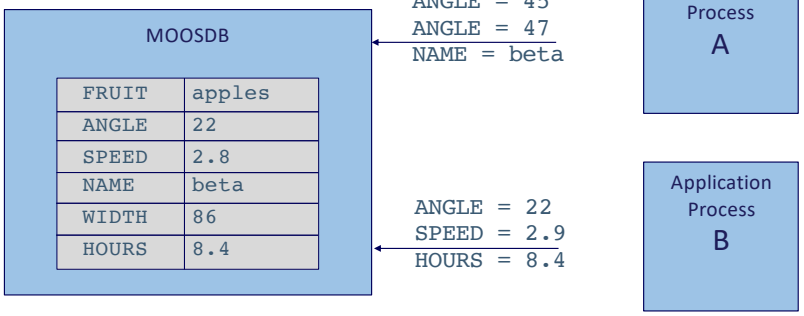
MOOS Apps Publish to the MOOSDB

- An App may publish to the MOOSDB any time
- No prior arrangement required

Note: Subscribers will get **all** postings – each as a new piece of mail.



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MOOS Apps Publish to the MOOSDB

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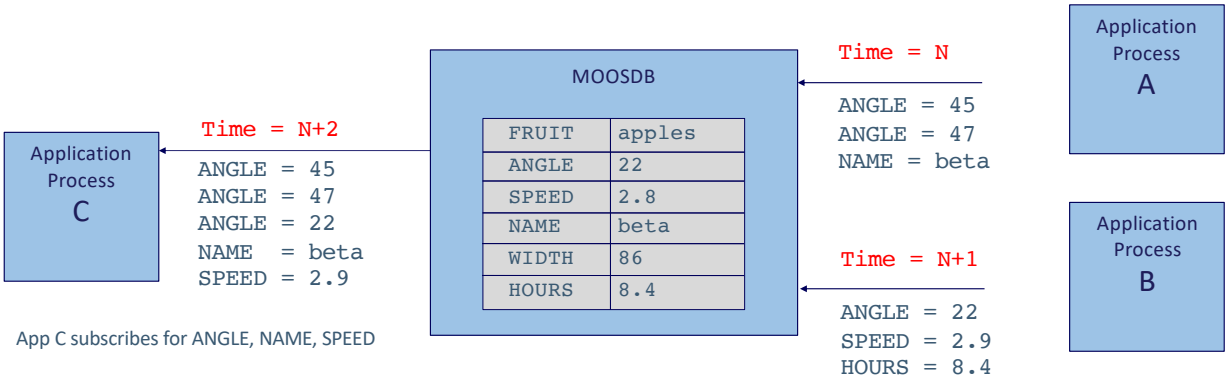

App C subscribes for ANGLE, NAME, SPEED

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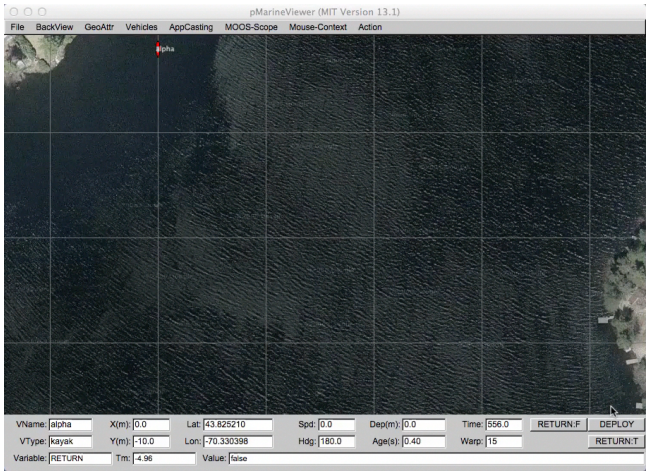
Example: The Alpha Mission

```
$ cd moos-ivp/ivp/missions/s1_alpha
$ ./launch.sh 10
```



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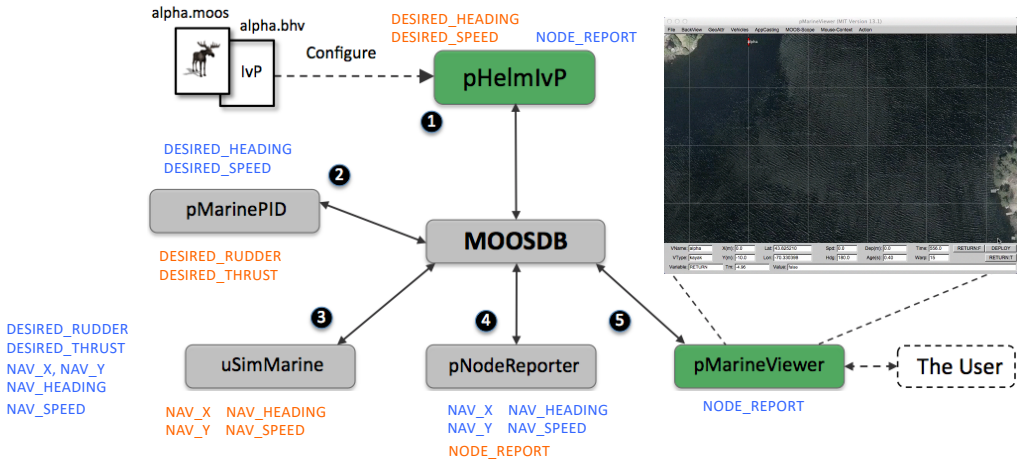
Alpha Mission

```
$ cd moos-ivp/ivp/missions/s1_alpha
$ ./launch.sh 10
```



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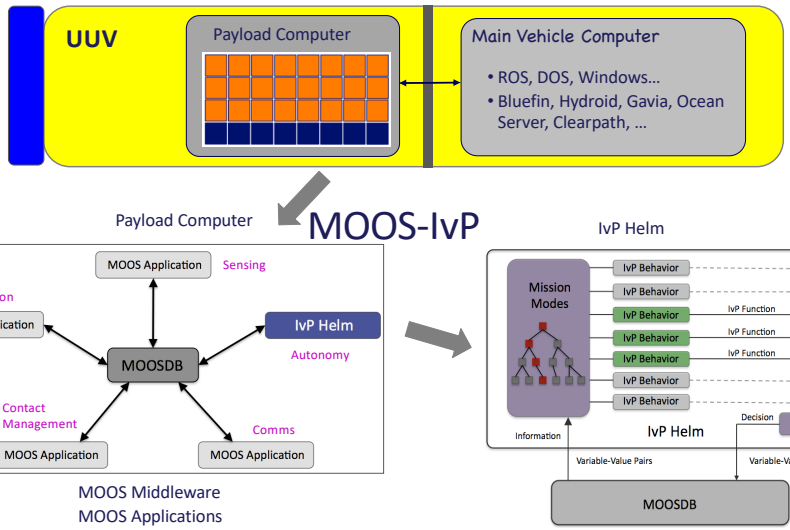
Payload Autonomy
(Another Architecture Perspective)



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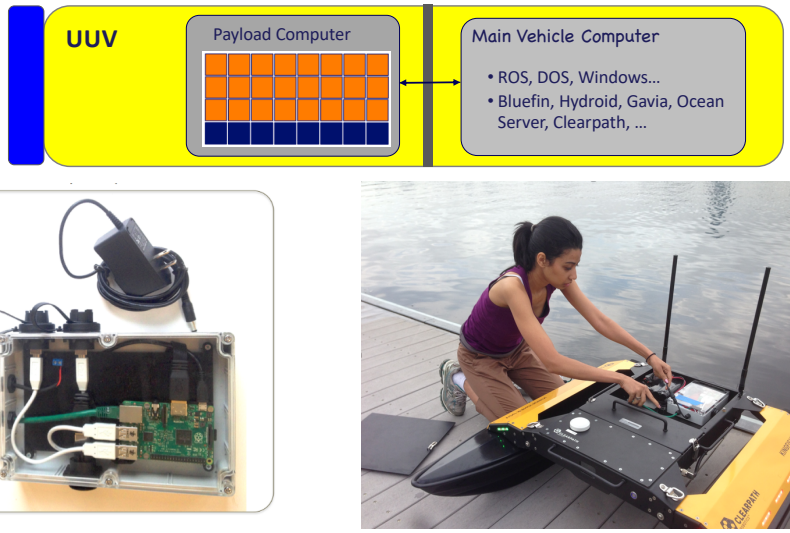
Payload Autonomy
(Another Architecture Perspective)



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Payload Autonomy on the Textron CUSV

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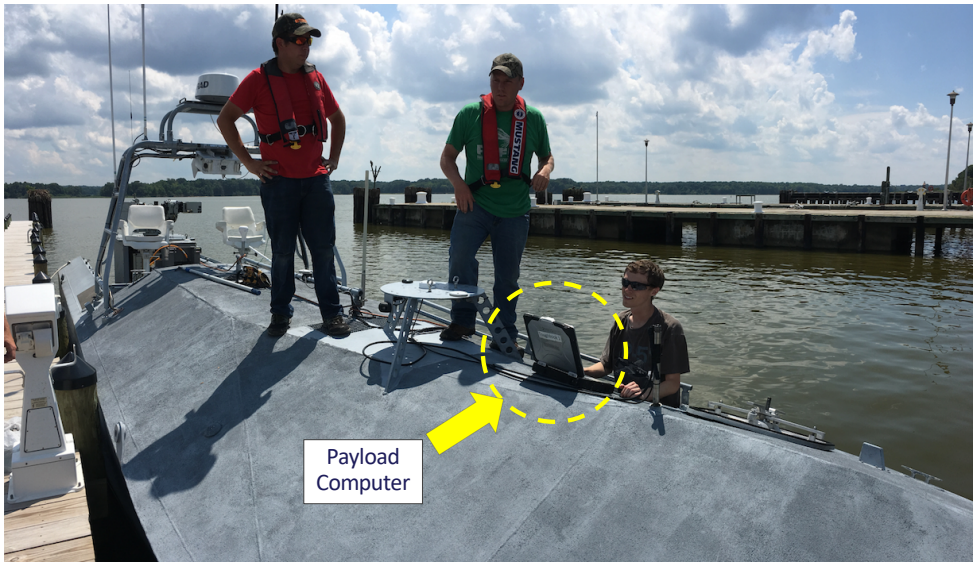

Sense-Plan-Act | Aquaticus Overview | Autonomy Architectures | Information Flow MOOS Intro | MOOS-IvP | Payload Autonomy | Lab 1 Overview

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MOOS-IvP Timeline ~20 Years

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2000 | 2002 | 2006 | 2007 | 2010 | 2011 | 2017 | 2018-2020

Core Ideas | MOOS-IvP Born | Beta Users | Wider Adoption, Training, Documentation | DoD/Commercial Users

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Application to Mine Countermeasure USVs

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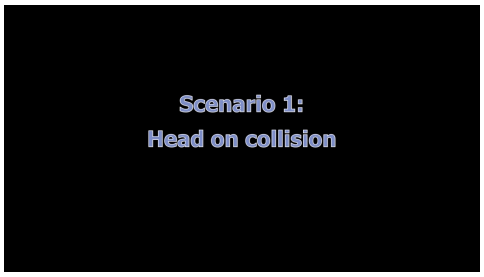
Textron Unmanned Systems MCM USV

Thales UK Halcyon



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Sea Machines, Boston

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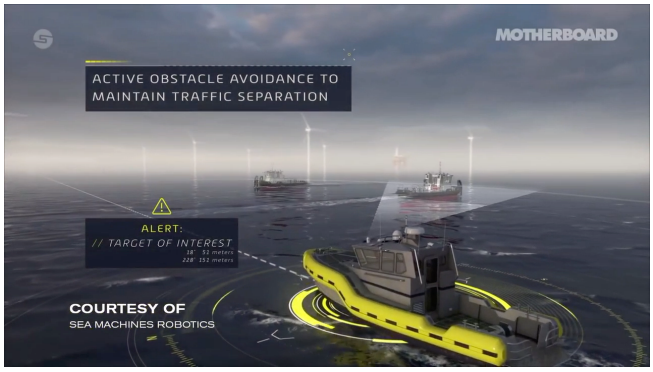
- In 2017 we began a collaboration with Sea Machines in Boston.
- Their SM300 Autonomy System is based on MOOS-IvP with substantial further SM investment on sensing and mission planning.
- Initial MOOS-IvP integration by our former post-doc.
- Subsequently hired 3 other former students
- They also have users in Denmark (autonomous fire boat):



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Rolls Royce / Finferries - "Autonomous Ferry"

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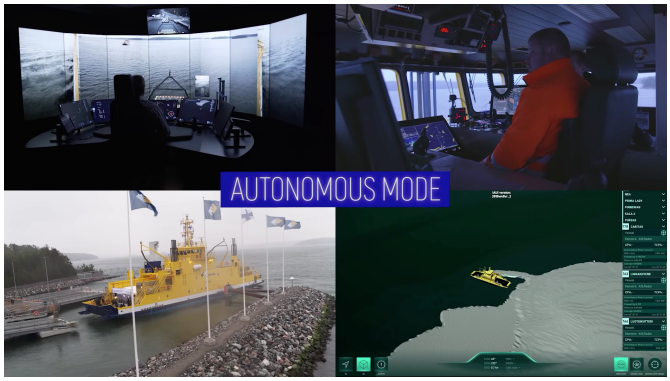
- December 2018: Rolls Royce, partnering with Finferries, claimed the world's first autonomous ferry.
- Sensor based COLREGS collision avoidance with other ships
- Uncontested transiting mode – Under Rolls Royce control
- Collision avoidance mode – Under MIT / MOOS-IvP control.



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Sense-Plan-Act in MOOS-IvP System

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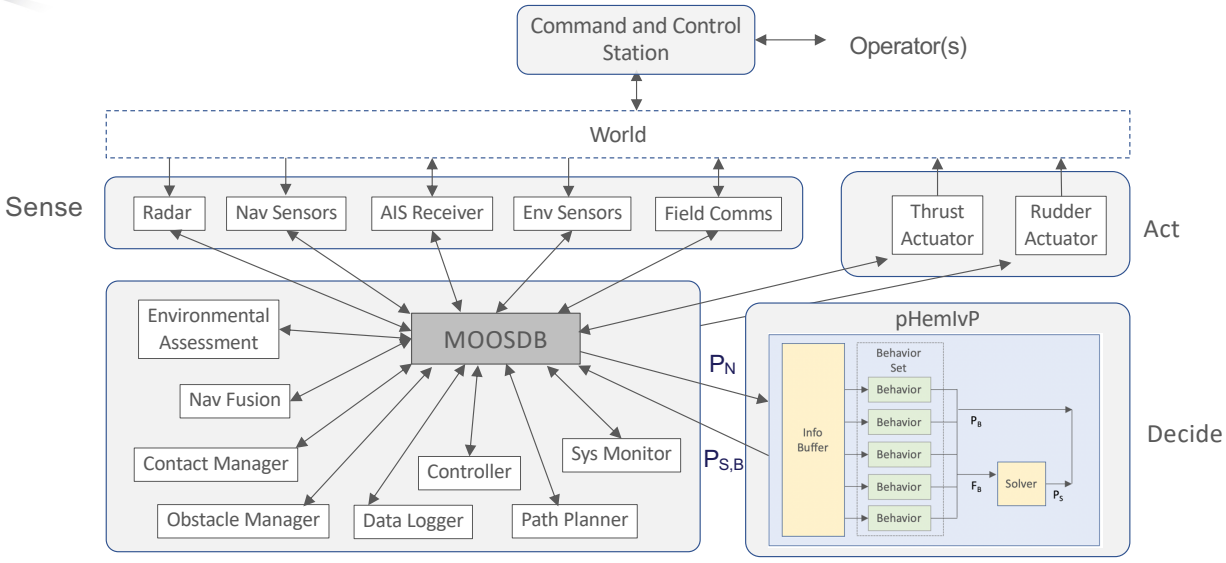

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Lab 1: Preview

Goals:

- Download and build the MOOS-IvP public codebase
- Confirm launch of the MOOS-IvP Alpha mission
- Download and build the MOOS-IvP Aquaticus codebase
- Confirm launch of the Aquaticus Alpha and Bravo Missions
- Explore Methods for Poking the MOOSDB
- Explore Methods for Scoping the MOOSDB
- Explore the launch script structures

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