Accelerated Marine Vehicle Autonomy, Sensing, and Communications

Spring 2019
2.014 Autonomy Mini-course

Introduction to the IvP Helm

Web: http://oceanai.mit.edu/pavlab/textron

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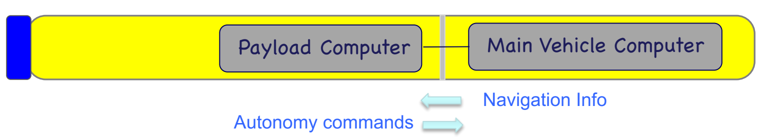
Payload UUV Autonomy

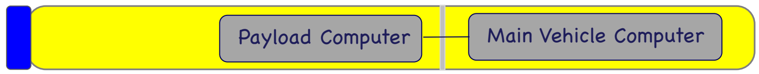
(3 Architecture Principles)

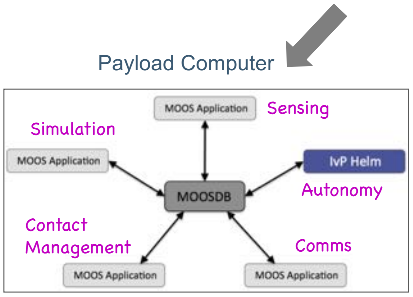


Architecture Principle #1
Payload Autonomy

Decouple the Procurement of Hardware and Software

Payload UUV Autonomy
(3 Architecture Principles)



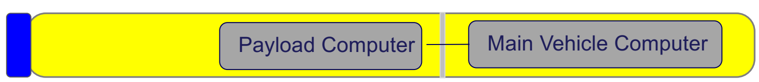


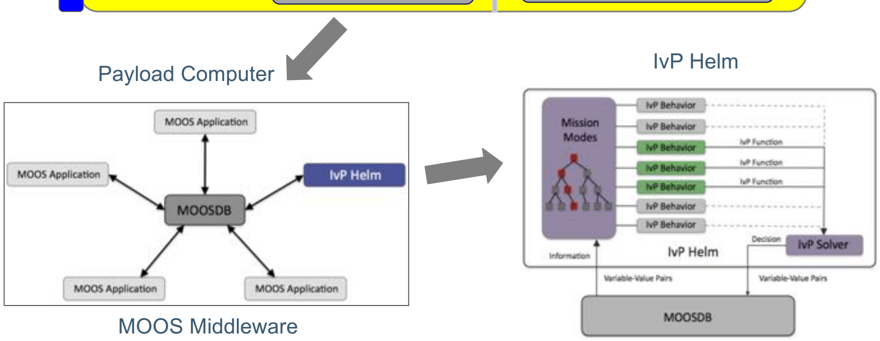
MOOS Middleware
MOOS Applications

Architecture Principle #2
Autonomy System Middleware

De-couple Software Procurements
Sensing, Autonomy, Simulation, Comms...

Payload UUV Autonomy
(3 Architecture Principles)



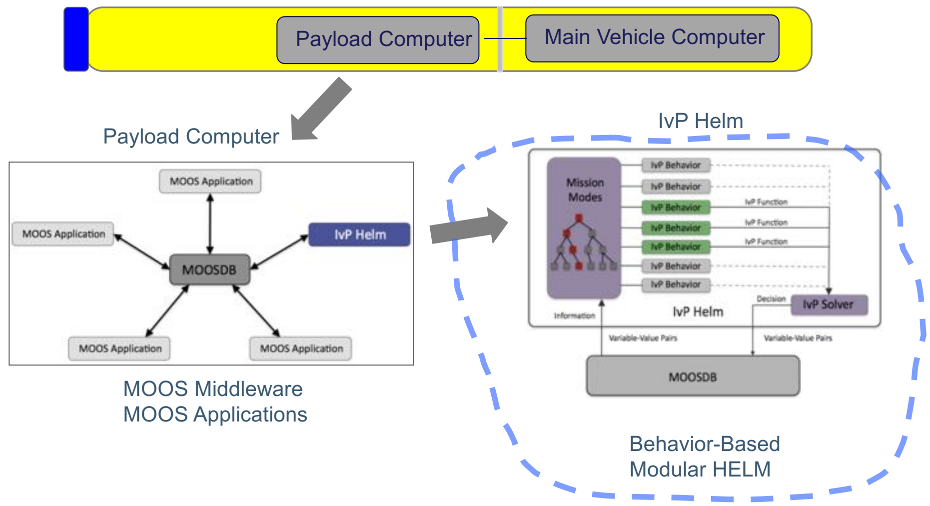


MOOS Middleware
MOOS Applications

Behavior-Based
Modular HELM

Payload UUV Autonomy

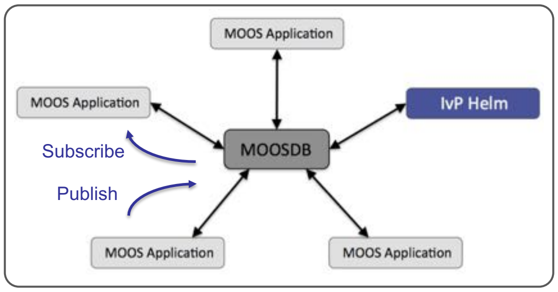
(3 Architecture Principles)



IvP Helm Overview

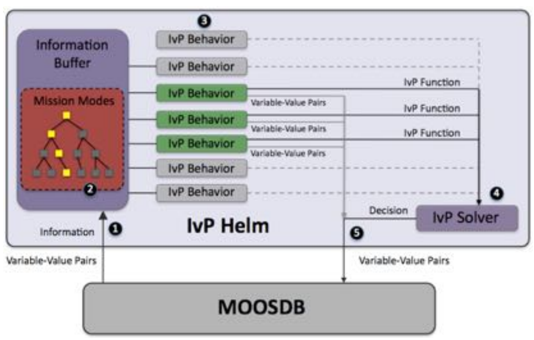
The IvP Helm

- The IvP Helm is a MOOS App, known as pHelmIvP
- The IvP Helm works with other MOOS Apps, performing sensor-processing, planning, communications.



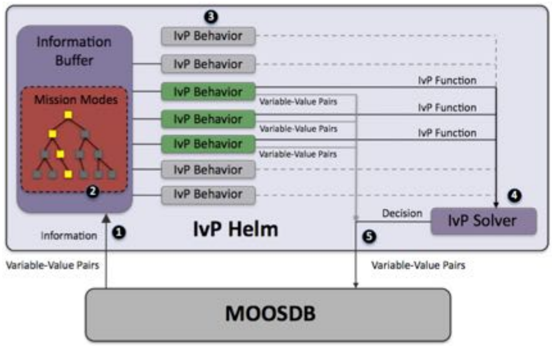
A MOOS Community

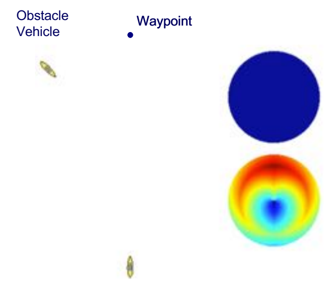
The IvP Helm Execution Loop



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.

The IvP Helm Execution Loop





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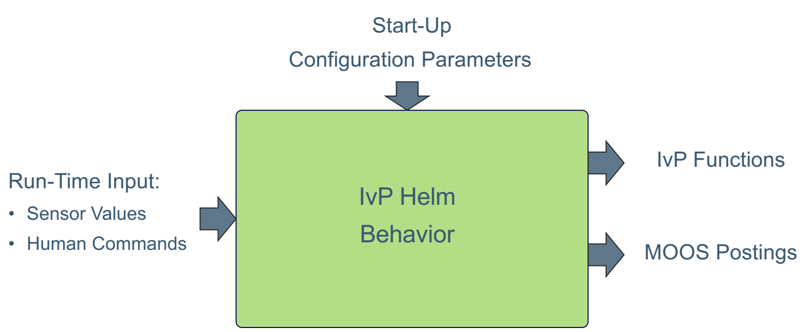
Behaviors Generally



Example: Waypoint Behavior

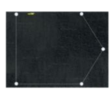
Start-Up
Configuration Parameters

Run-Time Input:
- Sensor Values
- Human Commands

IvP Functions

MOOS Postings

Behaviors Generally



- List of waypoints
- Desired speed
- Capture radius

Configuration Parameters

Run-Time Input:
- Sensor Values
- Human Commands

IvP Functions

MOOS Postings

Three Architectures | IvP Helm Overview | Alpha Mission | Behavior Files | Behavior Conditions | Behavior States | Behavior Flags

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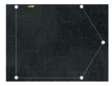
MIT Dept of Mechanical Engineering

Behaviors Generally



- List of waypoints
- Desired speed
- Capture radius

Configuration Parameters

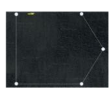
Run-Time Input

```
NAV_X = 237.98
NAV_Y = 1900.0
```

IvP Functions

MOOS Postings

Behaviors Generally



- List of waypoints
- Desired speed
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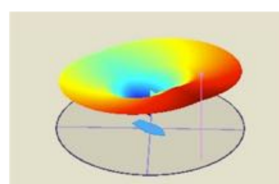
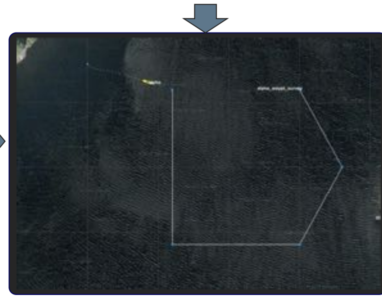


Configuration Parameters

Run-Time Input

```
NAV_X = 237.98
NAV_Y = 1900.0
```



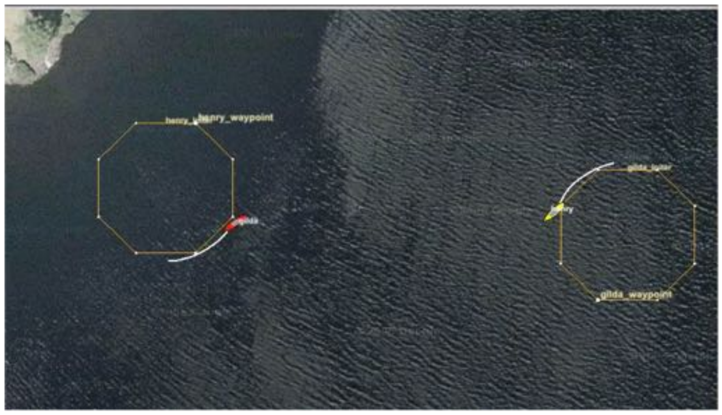
IvP Functions

MOOS Postings

```
WPT_INDEX  = 2
TRAVERSALS = 7
```

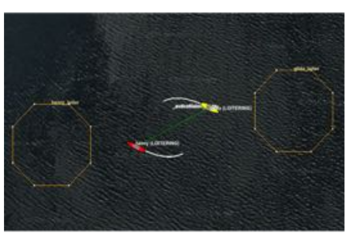
Competing Objective Functions

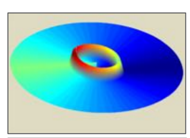
- An example of competing behaviors (1) Transiting and (2) Collision Avoidance



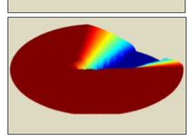
Competing Objective Functions

- Each vehicle is running two behaviors
- Each produces its own objective function





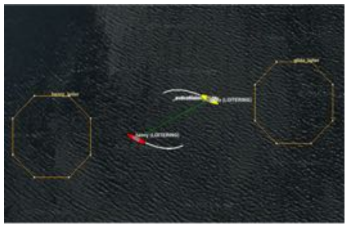
Transiting
Objective Function

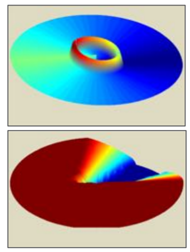


Collision Avoidance
Objective Function

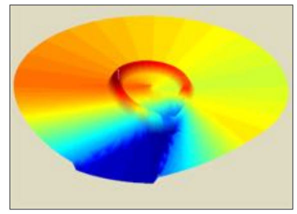
Competing Objective Functions

- Each vehicle is running two behaviors
- Each produces its own objective function





Individual
Objective Functions



Collective
Objective Function

Competing Objective Functions

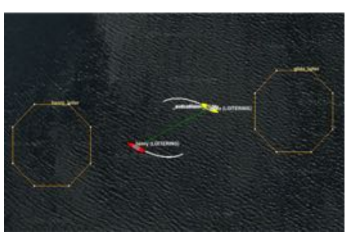
Behavior 1 → $f_1(x_1, x_2, \ldots, x_n)$
Behavior 2 → $f_2(x_1, x_2, \ldots, x_n)$
Behavior 3 → $f_3(x_1, x_2, \ldots, x_n)$

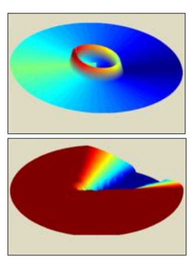
Individual
Objective Functions

$$\mathbf{x}^* = argmax_{\mathbf{x}} \sum_{i=1}^{k} (w_i \cdot f_i(\mathbf{x}))$$

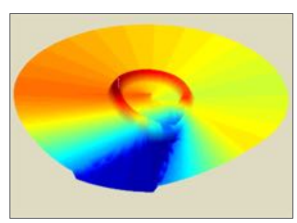
IvP Solver

→ Action





Individual
Objective Functions



Collective
Objective Function

Competing Objective Functions

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

Behavior 2 → $f_2(x_1,\ x_2,\ \ldots,\ x_n)$

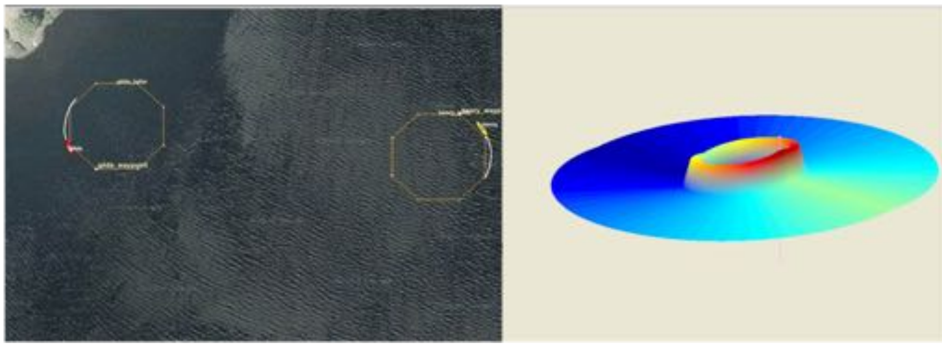
Behavior 3 → $f_3(x_1,\ x_2,\ \ldots,\ x_n)$

Individual Objective Functions

$$\mathbf{x}^* = argmax_{\mathbf{x}} \sum_{i=1}^{k} (w_i \cdot f_i(\mathbf{x}))$$

IvP Solver

→ Action

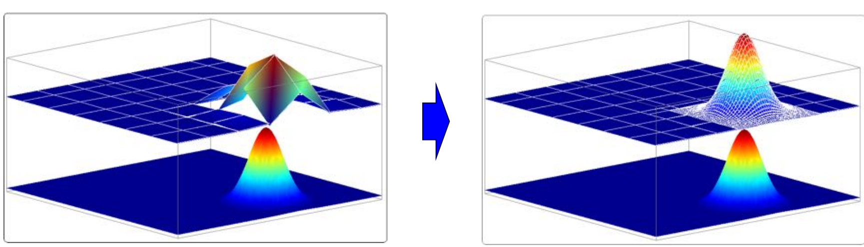


Interval Programming

- IvP is Interval Programming
- It is a format for representing objective functions
- It is a solver that capitalizes on that format – fast, globally optimal

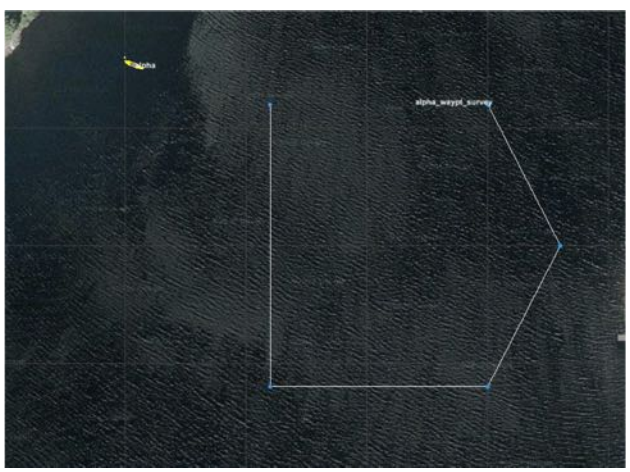
IvP Functions are piecewise linear

Piece distribution need not be uniform



The Alpha Mission

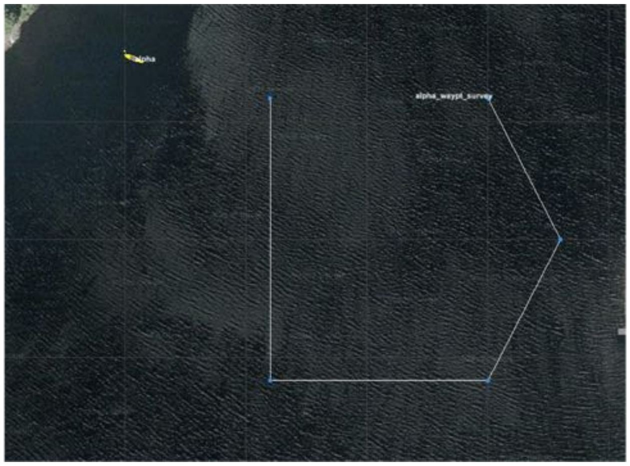
The Alpha Mission

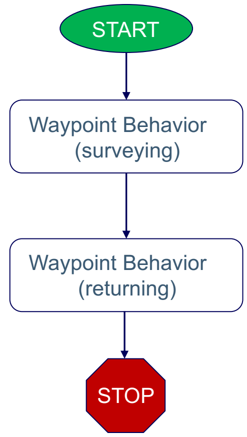


To launch yourself:

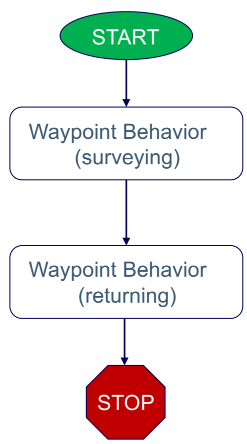
```
$ cd moos-ivp/ivp/missions/s1_alpha
$ ./launch.sh 10
```

Alpha Mission Has Two Behaviors





Alpha Mission Has Two Behaviors

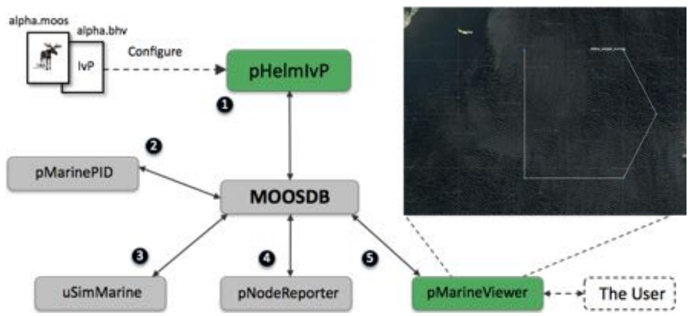


Three questions discussed next:

- How is this mission configured?
- What initiates this mission?
- How does the helm transition to return?

Configuring the Helm for a Mission

A mission is configure with two files:
- `alpha.moos` – configures all MOOS apps, including general helm parameters
- `alpha.bhv` – configures all Helm behaviors



To launch yourself:

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$ cd moos-ivp/ivp/missions/s1_alpha
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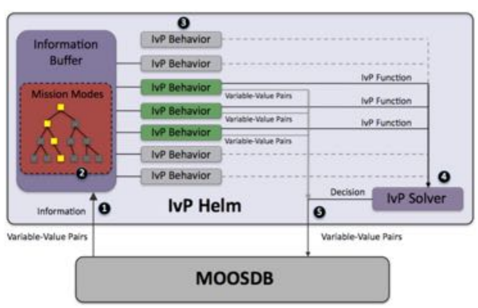
Behavior Files



Helm configuration file structure:

file.bhv
- Variable Initializations
- Behavior Configuration
- ⋮
- Behavior Configuration

```
Behavior = <behavior_name>
{
   parameter = value
   . . .
   parameter = value
}
```

Alpha Mission Behavior File

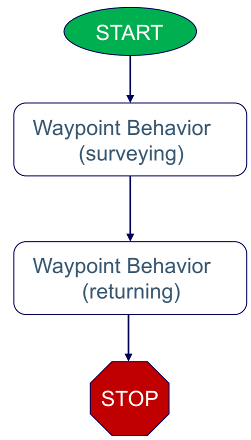
```
initialize   DEPLOY = false
initialize   RETURN = false
```

```
Behavior = BHV_Waypoint
{
  name      = waypt_survey
  pwt       = 100
  condition = RETURN = false
  condition = DEPLOY = true
  endflag   = RETURN = true

           speed = 4
  capture_radius = 5.0
     slip_radius = 15.0
         polygon = 60,-40:60,-160:150,-160:180,-100:150,-40
         repeat  = 1
}
```

```
Behavior = BHV_Waypoint
{
  name       = waypt_return
  pwt        = 100
  condition  = RETURN = true
  condition  = DEPLOY = true
  endflag    = DEPLOY = false

           speed = 2.0
  capture_radius = 2.0
     slip_radius = 8.0
          points = 0,-2
}
```



Helm Initial MOOSDB Pokes

alpha.bhv file

```
initialize   DEPLOY = false
initialize   RETURN = false
```

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  condition  = DEPLOY = true
  endflag    = DEPLOY = false

           speed = 2.0
  capture_radius = 2.0
     slip_radius = 8.0
           point = 0,-2
}
```

When pHelmIvP launches,
it will write to the MOOSDB:

```
DEPLOY = false
RETURN = false
```

Behavior Types vs. Names

alpha.bhv file

```
initialize   DEPLOY = false
initialize   RETURN = false
```

```
Behavior = BHV_Waypoint
{
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}
```

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Behavior = BHV_Waypoint
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  condition  = DEPLOY = true
  endflag    = DEPLOY = false

         speed = 2.0
  capture_radius = 2.0
     slip_radius = 8.0
           point = 0,-2
}
```

Both behaviors are the *same type.*

Each behavior has a *unique name.*

Waypoint Behavior Points

alpha.bhv file

```
initialize   DEPLOY = false
initialize   RETURN = false
```

```
Behavior = BHV_Waypoint
{
  name      = waypt_survey
  pwt       = 100
  condition = RETURN = false
  condition = DEPLOY = true
  endflag   = RETURN = true

         speed = 4
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     slip_radius = 15.0
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}
```

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Behavior = BHV_Waypoint
{
  name       = waypt_return
  pwt        = 100
  condition  = RETURN = true
  condition  = DEPLOY = true
  endflag    = DEPLOY = false

         speed = 2.0
  capture_radius = 2.0
     slip_radius = 8.0
           point = 0,-2
}
```

The waypoint behavior accepts either:

- *a polygon*
- *a single point*

Behavior Conditions

Behavior Conditions

- Each condition involves one or more MOOS variables
- A behavior may have more than one condition
- If multiple conditions, all conditions need to be satisfied.

Example:

```
condition = RETURN = false
condition = DEPLOY = true
```

- Both `RETURN` an `DEPLOY` are MOOS variables
- Both are of type string (not double)
- The condition is true if the current variable value matches the string

Behavior Conditions

- Each condition involves one or more MOOS variables
- A behavior may have more than one condition
- If multiple conditions, all conditions need to be satisfied.

alpha.bhv file

```
initialize   DEPLOY = false
initialize   RETURN = false
```

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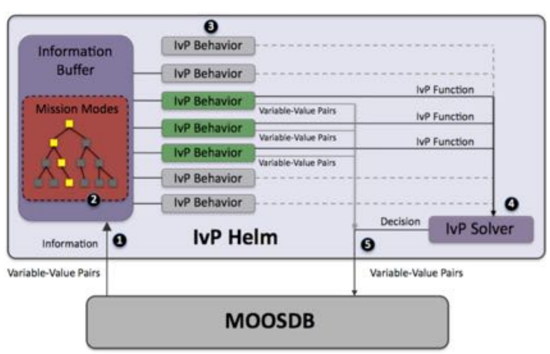
           speed = 4
  capture_radius = 5.0
     slip_radius = 15.0
         polygon = 60,-40:60,-160:150,-160:180,-100:150,-40
         repeat  = 1
}
```


The Helm Information Buffer

- The helm maintains an information buffer, a cache of MOOS Variable Values
- It is updated by reading MOOS mail on each iterate loop
- Behavior Conditions are checked against this buffer



The Helm Information Buffer

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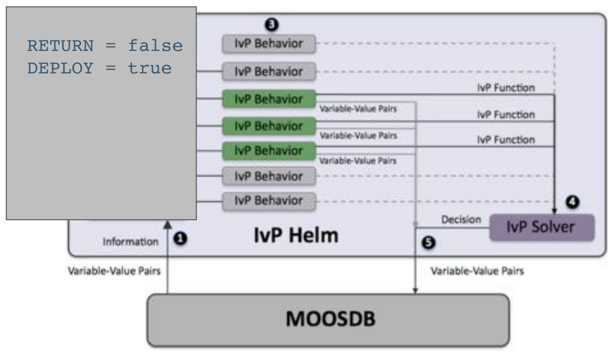


Behavior Logic Conditions

Simple logic condition with one component

```
condition = RETURN = false
```

true if the MOOS variable RETURN has the string value “false”

```
condition = DEPLOY != true
```

true if the MOOS variable DEPLOY has a string value other than “true”

WARNING: this condition is fail if the MOOS variable DEPLOY has never been written to.

Disjunctive (OR) Logic Conditions

A logic condition may have more than one component

```
condition = ((RETURN = false) or (DEPLOY != true))
```

True if

- the MOOS variable RETURN has the string value “false”, OR
- the MOOS variable DEPLOY has a string value other than “true”

WARNING: this condition will fail if the MOOS variable DEPLOY has never been written to – even if the first component (`RETURN = false`) is true

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)and(RETURN=false)

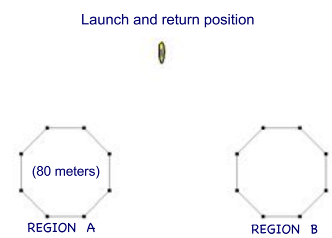
     speed = 1.8
    radius = 4.0
   polygon = format=radial,x=0,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Loiter
{
  name      = loiter_b
  condition = (DEPLOY=true)and(REGION=B)and(RETURN=false)

     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
```

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)and(RETURN=false)

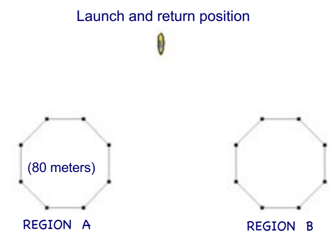
      speed = 1.8
     radius = 4.0
    polygon = format=radial,x=0,y=-75,radius=40,pts=8
}
```

```
Behavior = BHV_Loiter
{
  name      = loiter_b
  condition = (DEPLOY=true)and(REGION=B)and(RETURN=false)

      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)

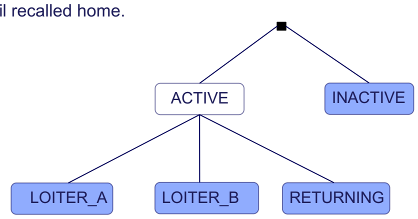
      speed = 1.8
      radius = 4.0
       point = 80,40
}
```

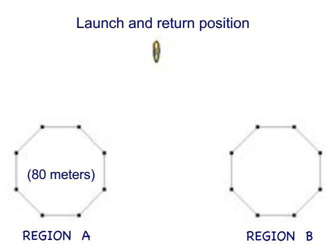



```
Initialize  DEPLOY = false
Initialize  RETURN = false
Initialize  REGION = A
```


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.





Simple Example: "Double Loiter"

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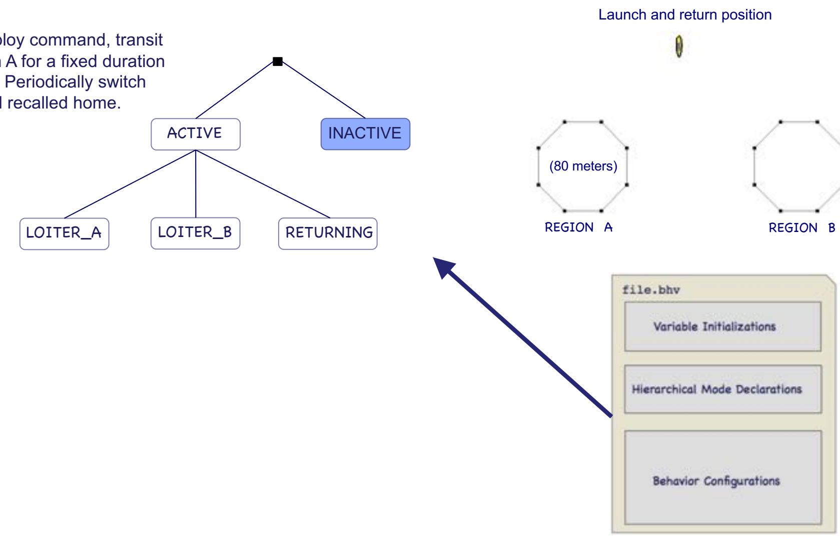

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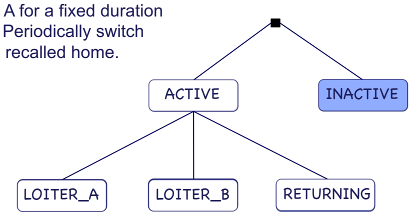
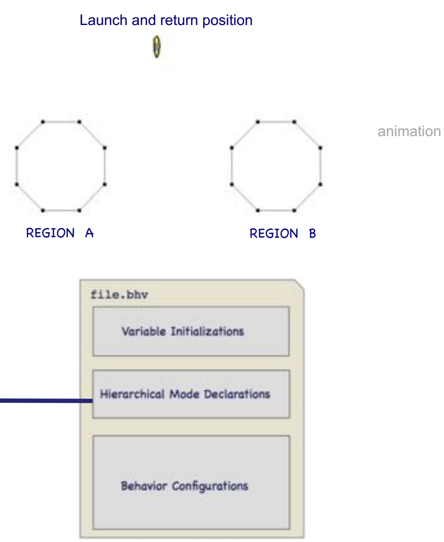
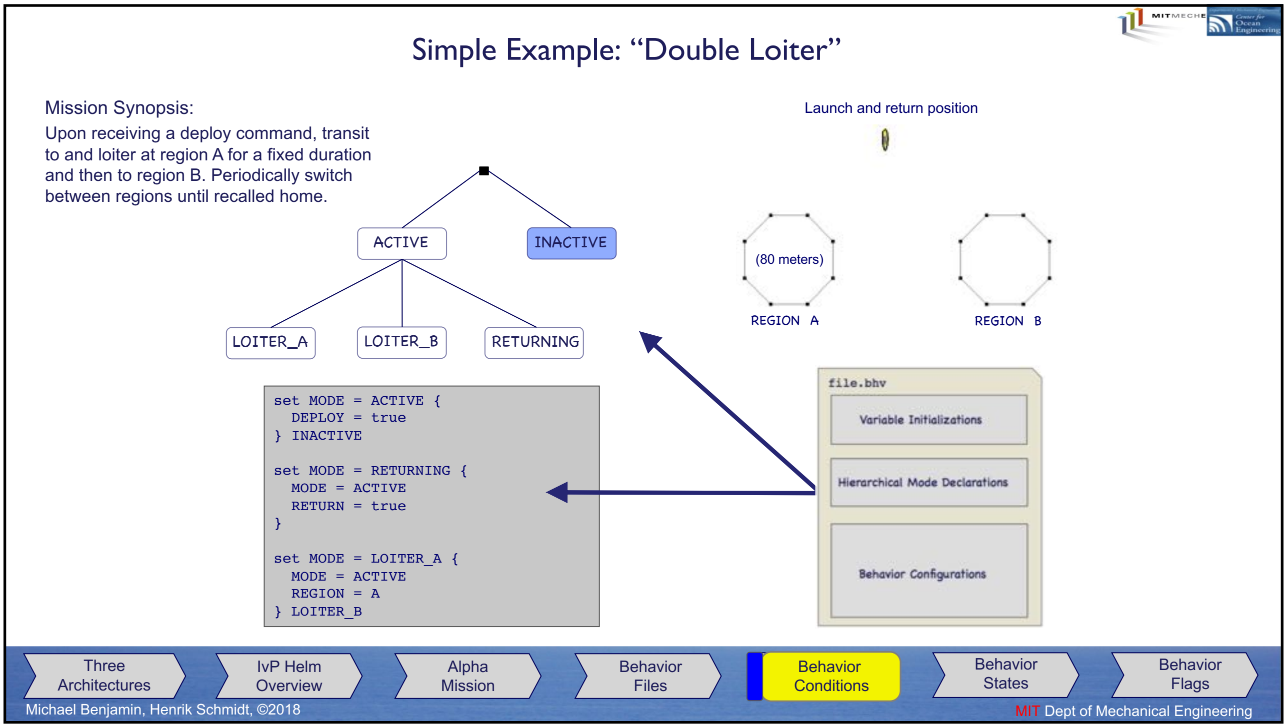



```
set MODE = ACTIVE {
  DEPLOY = true
} INACTIVE

set MODE = RETURNING {
  MODE = ACTIVE
  RETURN = true
}

set MODE = LOITER_A {
  MODE = ACTIVE
  REGION = A
} LOITER_B
```




Simple Example: "Double Loiter"
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INACTIVE
LOITER_A
LOITER_B
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} LOITER_B
Launch and return position
(80 meters)
REGION A
REGION B
file.bhv
Variable Initializations
Hierarchical Mode Declarations
Behavior Configurations
Three Architectures
IvP Helm Overview
Alpha Mission
Behavior Files
Behavior Conditions
Behavior States
Behavior Flags
Michael Benjamin, Henrik Schmidt, ©2018
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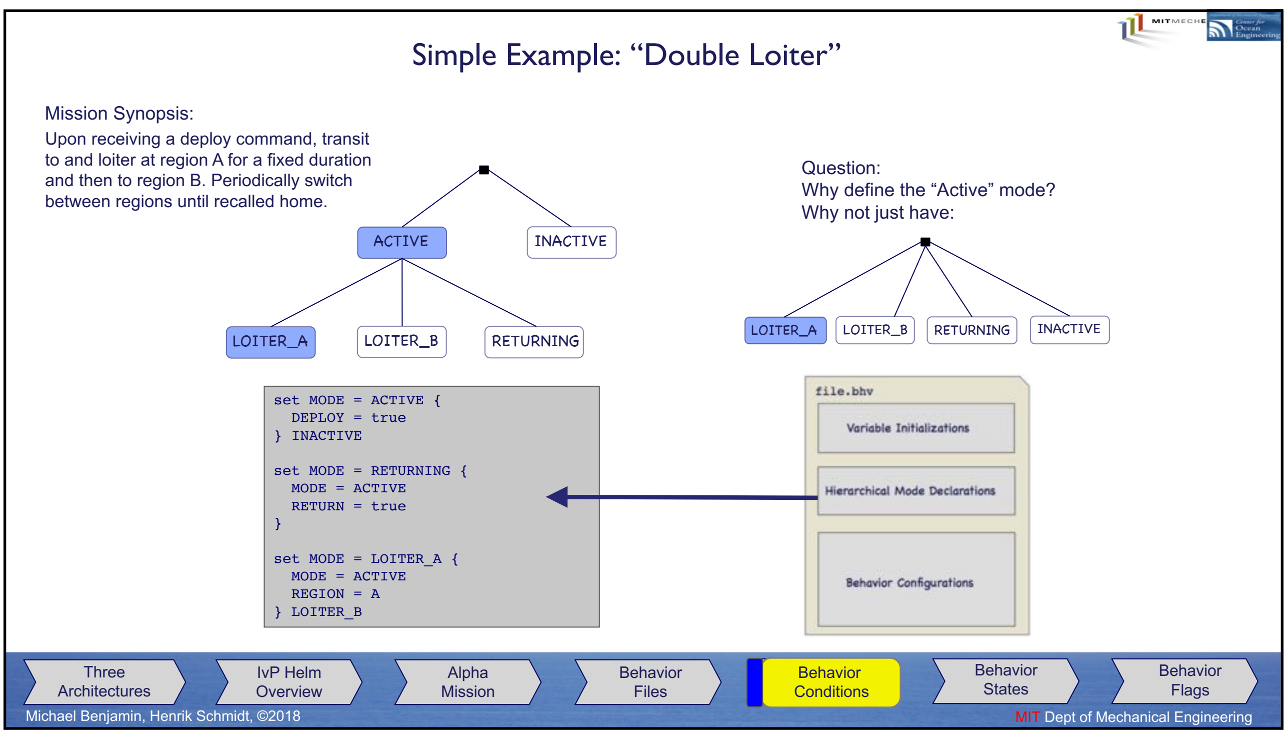
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  MODE = ACTIVE
  REGION = A
} LOITER_B
Question:
Why define the "Active" mode?
Why not just have:
LOITER_A
LOITER_B
RETURNING
INACTIVE
file.bhv
Variable Initializations
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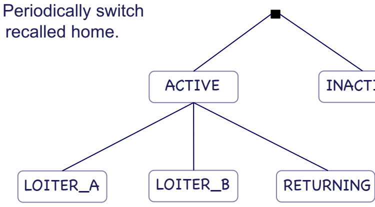

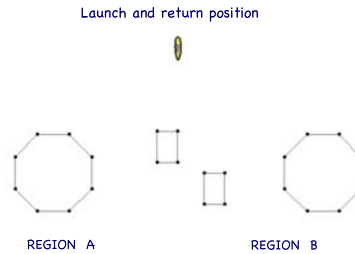


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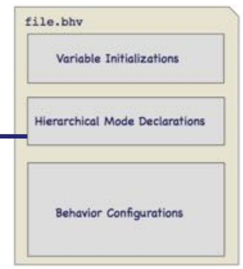
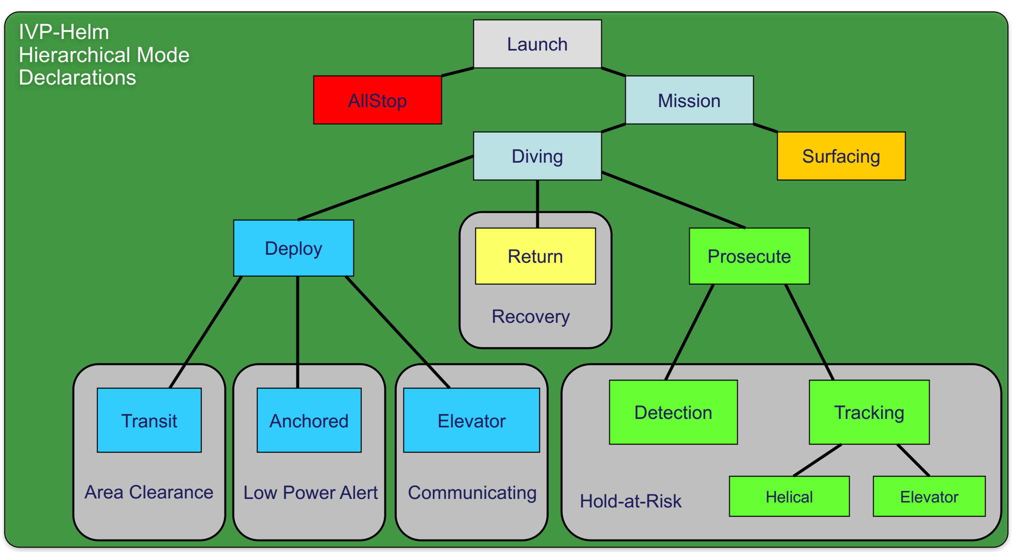


MIT Prototype Autonomy Modes



Behavior States

Behavior States

Behaviors may be in one of four states:

Idle | Running Active | Completed

The idle state: a behavior has not met its run condition, as defined by the condition parameter.

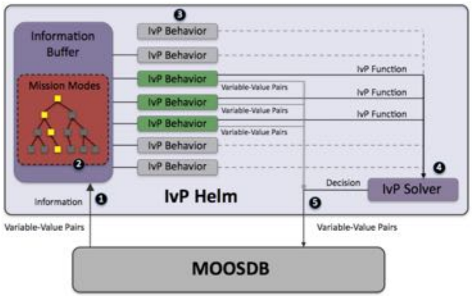
The running state: a behavior has met its run conditions

The active state: a behavior is running state and is producing an objective function

The completed state: Completion is specific to a behavior, or may be due to a duration timeout defined generally for all behaviors.

Active vs. Running States

Idle | Running | Active | Completed



The running state: behavior has met its run conditions.
The active state: behavior is running and producing an objective function.

The helm's primary job is to produce a helm decision. A behavior is participating in that decision only if it is producing an objective function.

A behavior may participate in the helm decision based on:

(1) The run conditions (mostly dependent on an external decision process)

(2) The behavior's own logic (a local decision based on a more nuanced understanding of the situation).

Active vs. Running States

What is the difference between running and active?

Idle | Running | Active | Completed

The running state: behavior has met its run conditions.
The active state: behavior is running and producing an objective function.

The helm's primary job is to produce a helm decision. A behavior is participating in that decision only if it is producing an objective function.

The choice to participate in the helm decision is made at two points:

(1) The run conditions (mostly dependent on an external decision process)

(2) The behavior's own logic (a local decision based on a more nuanced / domain-expert understanding of the situation).

Behavior Flags

Behavior Flags

- Flags are MOOS Pokes triggered by behavior state
- The are mission configuration parameters (not behavior source code)
- The are critical tools for structuring a mission

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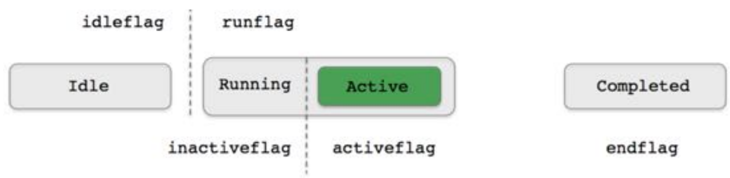


endflag: posted when the behavior completes.
idleflag: posted when the behavior is in the idle state.
runflag: posted when the behavior is in the running (or active) state.
activeflag: posted when the behavior is in the active state.
inactiveflag: posted when the behavior is not in the active state.
activeflag: posted when the behavior is in the active state.

End Flags

- End Flags are posted when a behavior completes
- An endflag may trigger the condition of another behavior
- Alpha mission as an example. The end of the survey behavior triggers the start of the return behavior.

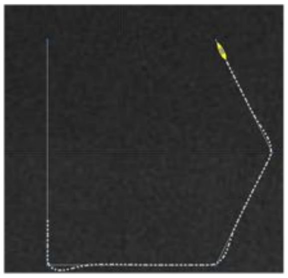
```
Behavior = BHV_Waypoint
{
  name      = waypt_survey
  pwt       = 100
  condition = RETURN = false
  condition = DEPLOY = true
  endflag   = RETURN = true

           speed = 4
  capture_radius = 5.0
     slip_radius = 15.0
         polygon = 60,-40:60,-160:150,-160:180,-100:150,-40
         repeat  = 1
}
```

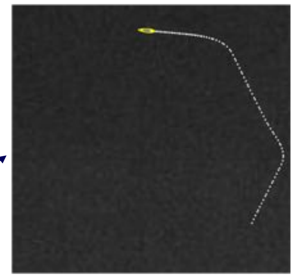
```
Behavior = BHV_Waypoint
{
  name        = waypt_return
  pwt         = 100
  condition   = RETURN = true
  condition   = DEPLOY = true
  endflag     = DEPLOY = false

           speed = 2.0
  capture_radius = 2.0
     slip_radius = 8.0
           point = 0,-2
}
```

Alpha Mission End Flag Example



1. survey waypoints completes
2. endflags posted `RETURN=true`
3. return waypoint behavior begins



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}
```


END

Behavior Completion

Behaviors states:

Idle | Running Active | Completed

Completion is defined by the behavior. For example:

- A waypoint behavior *completes* when it has visited all its waypoints.
- A loiter behavior never *completes*.

Even behaviors that don't normally *complete*, may complete when configured with a prescribed duration, e.g., duration=60 // seconds

By default, a completed behavior simply ceases to exist once it is completed. No chance for participation ever again in the helm.

Unless… the behavior is configured with perpetual=true.

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