Cooperative Seabed Coverage with MOOS-IvP, LCM, iSAM, Goby, and HoverAcomms

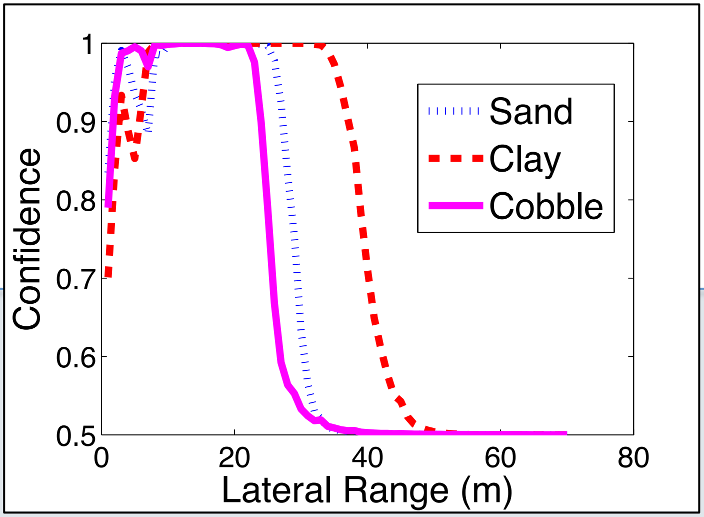
MOOS-DAWG 2015

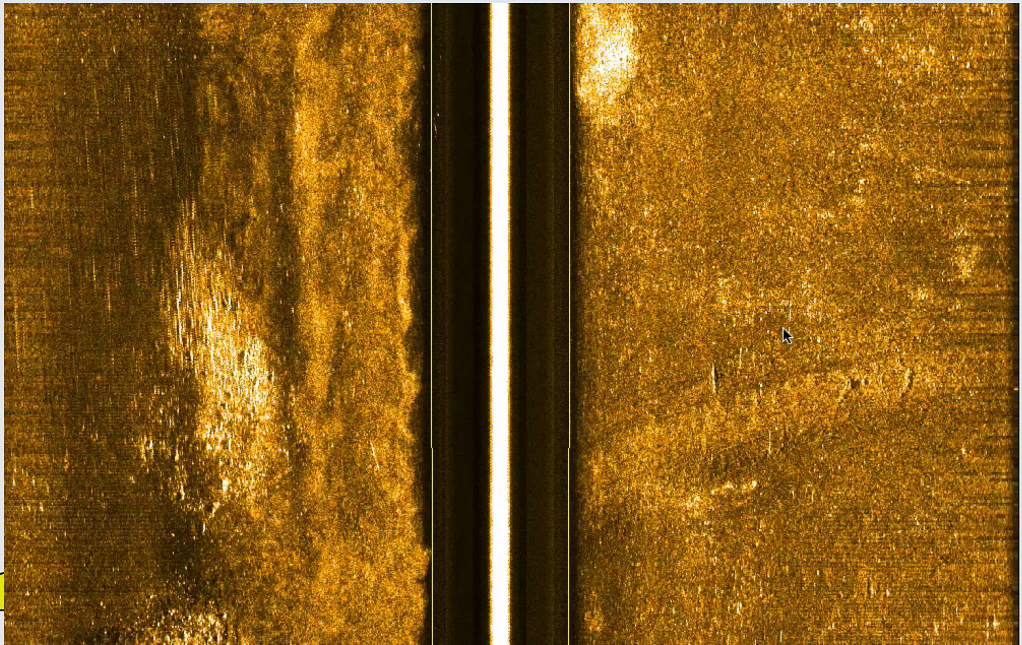
July 22, 2015

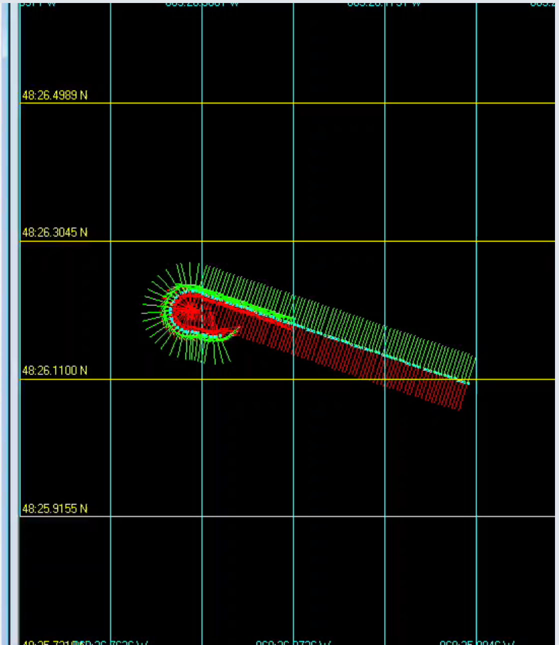
Presenter: Liam Paull

Collaborators: Mae Seto, John Leonard, and many many more…

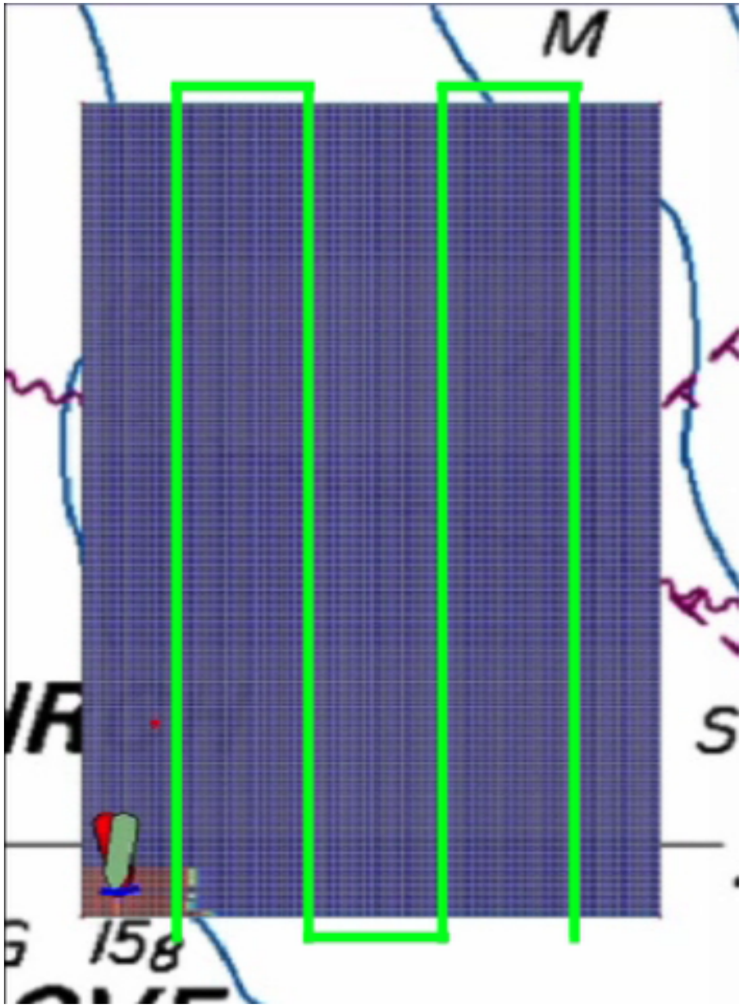
Seabed Imaging with the Sidescan Sonar







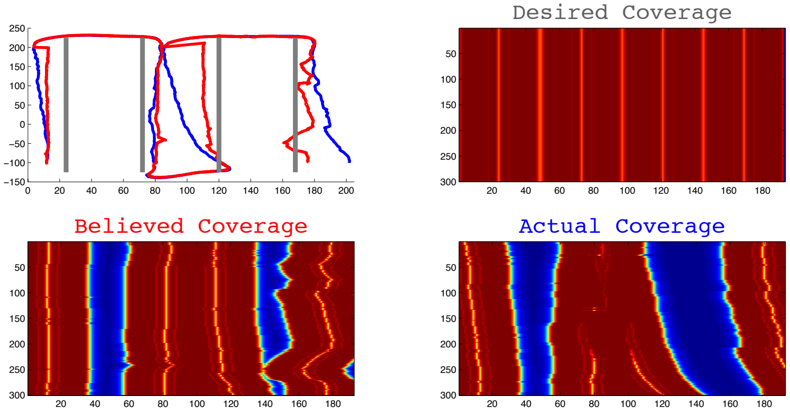
Seabed Imaging Survey with Poor Navigation



Actual field data of an AUV mapping an area of seabed.

- Red = actual location
- Green = estimated location (fusing compass and DVL data with an EKF)

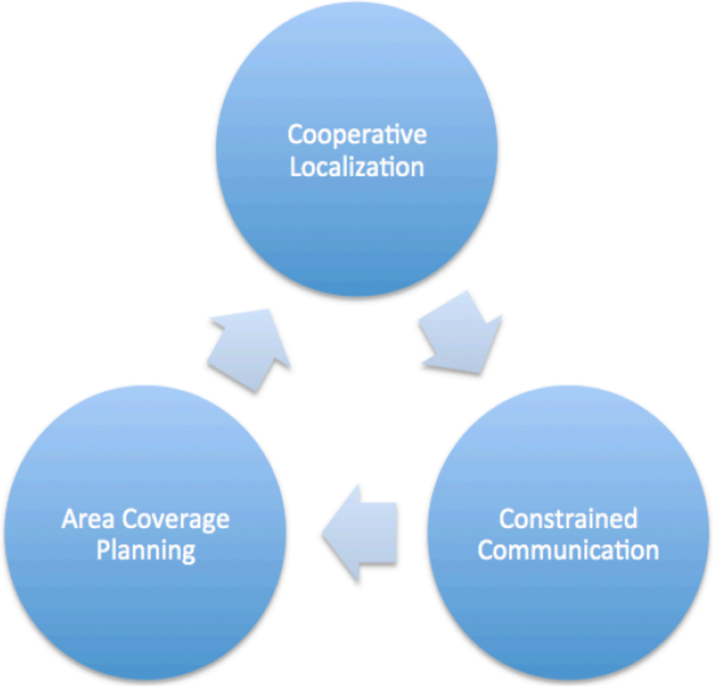
Many areas are missed!



Mine Countermeasures

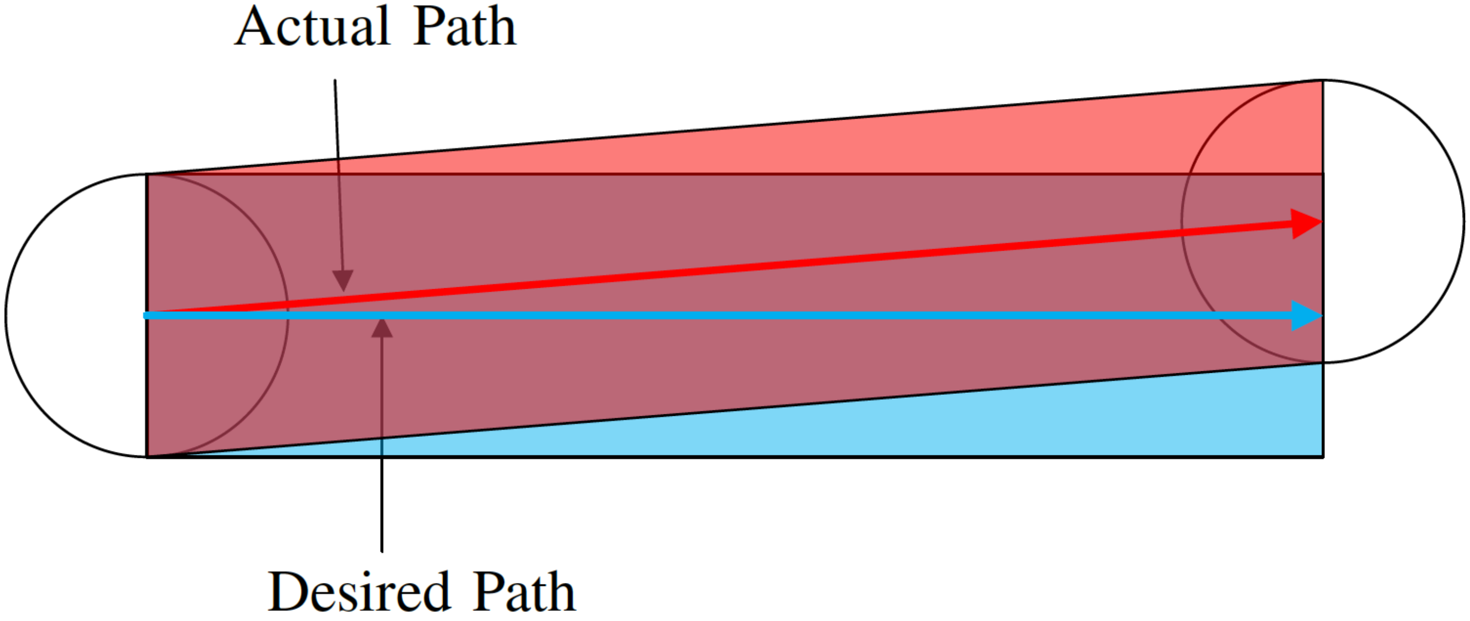
Outline

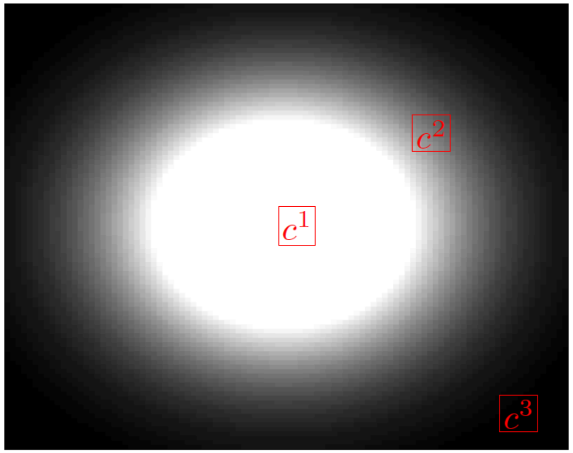
- ~~Introduction~~
- Robust Area Coverage
- Decentralized Cooperative Trajectory Estimation
- Online Adaptive Planning
- Experimental Setup
- Preliminary Results



Packet generation and planning are “in the loop” – everything runs in real-time on the vehicle

Robust Area Coverage

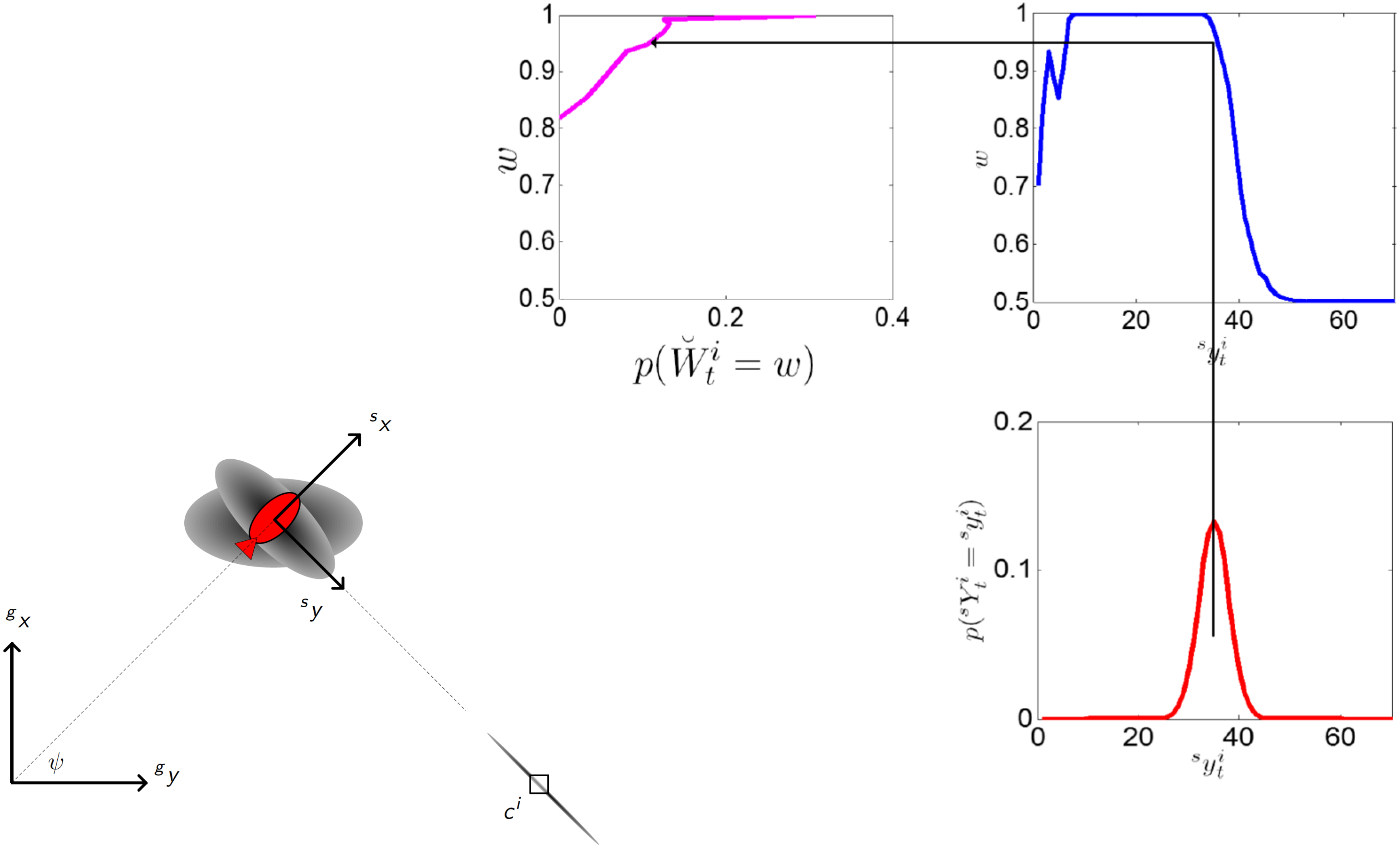




- Area to be covered is discretized into cells
- Each cell has an associated random variable which represents it's probability of being covered

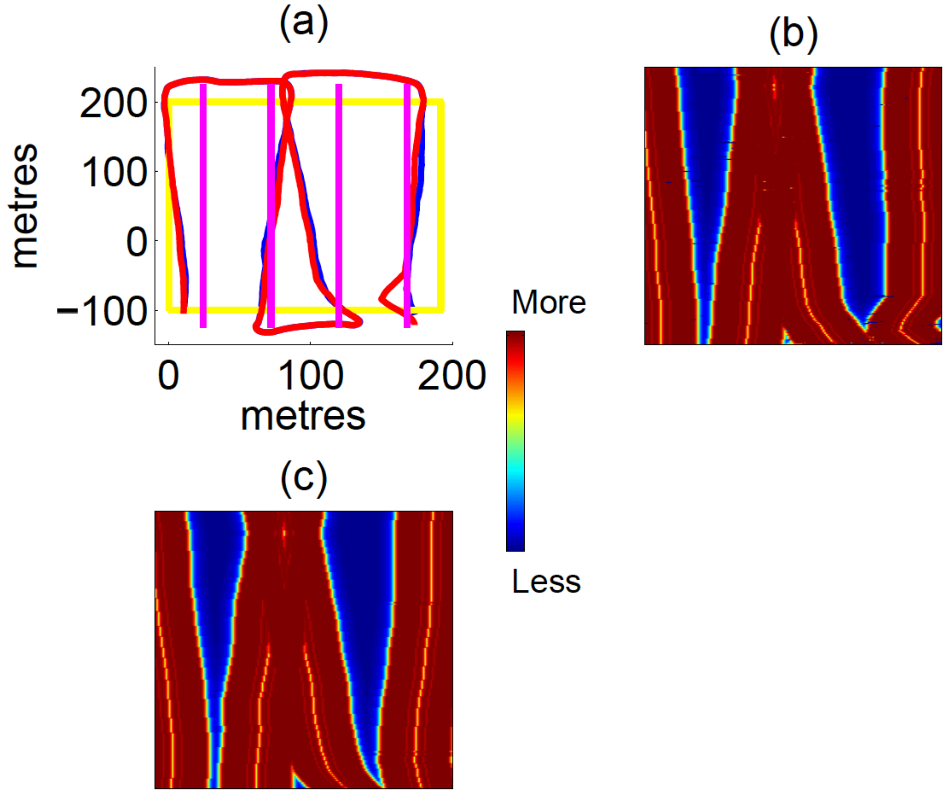
Key Idea: As long as the vehicle estimate is consistent, then probabilistic coverage implies actual coverage

Robust Area Coverage – The AUV Seabed Imaging Case



Robust Area Coverage – Full Trajectory Estimation

- We can minimize the discrepancy between the **believed** coverage and **actual** coverage by estimating the entire vehicle trajectory.



(a) Actual and estimated paths
(b) Estimated coverage
(c) Actual coverage

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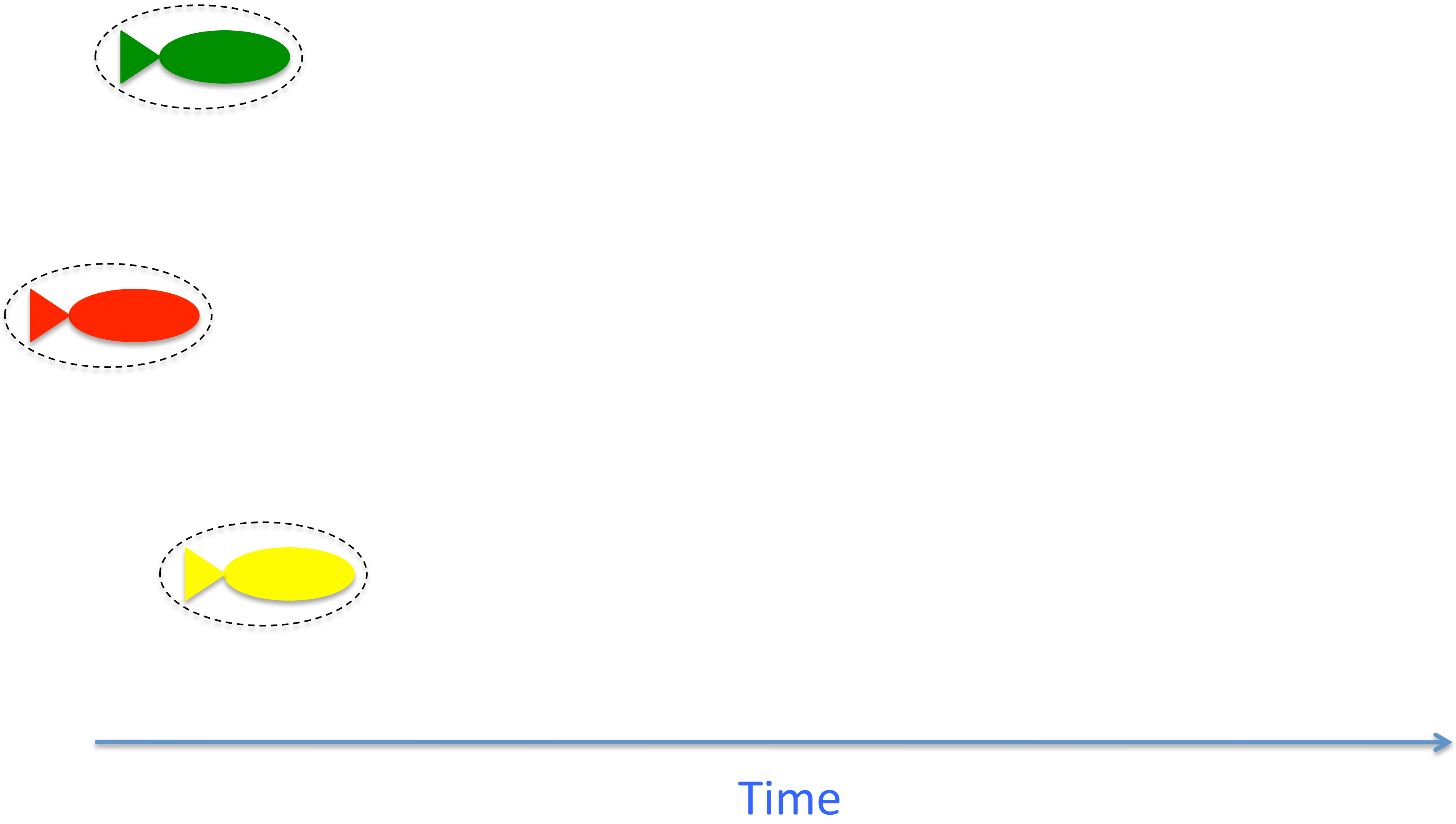
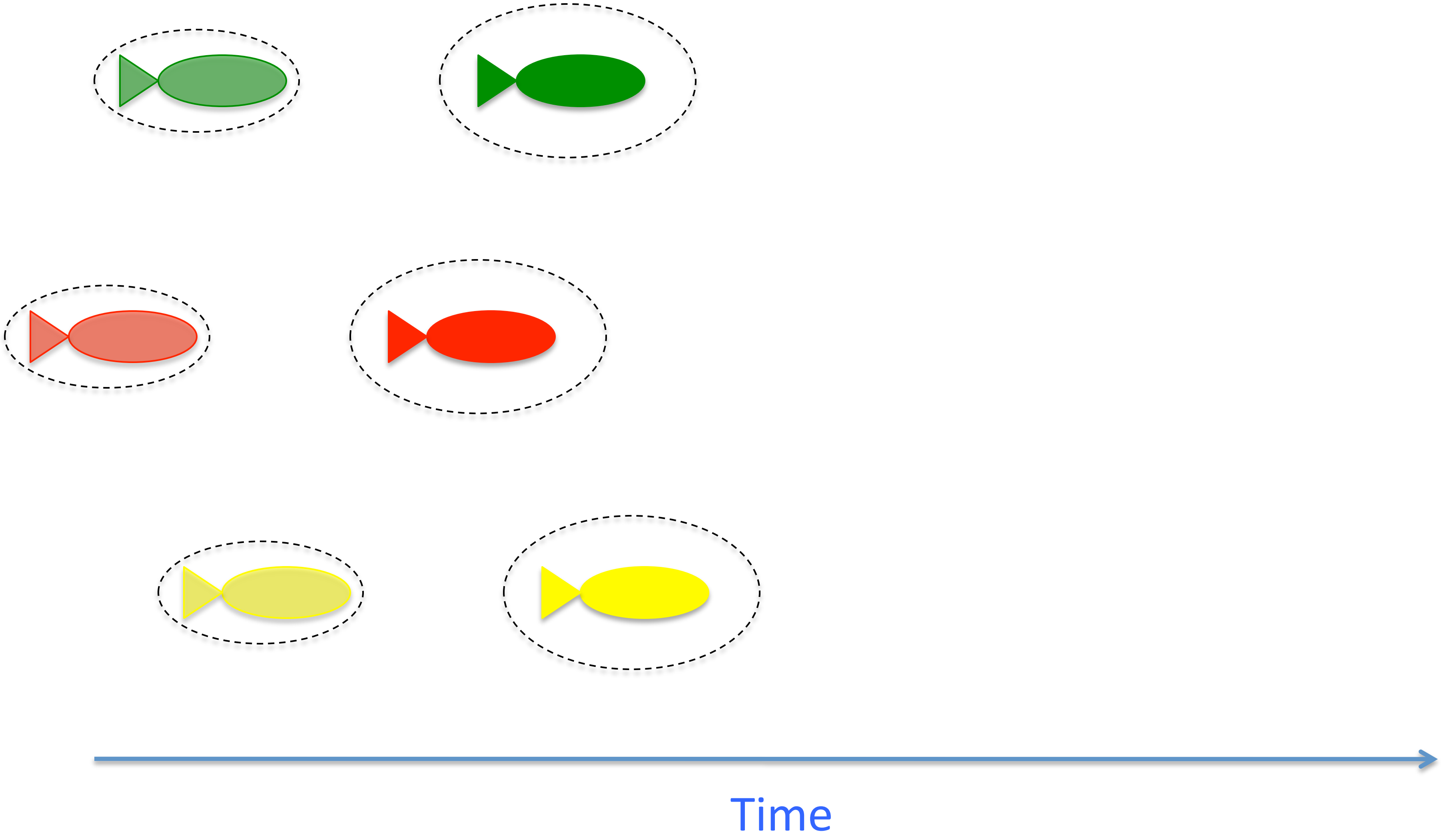
Cooperative Trajectory Estimation

- The area coverage problem is inherently partitionable – but we can do even better if the vehicles can communicate and make relative measurements
- But acoustic communications is very challenging

Underwater Cooperative Localization



Underwater Cooperative Localization



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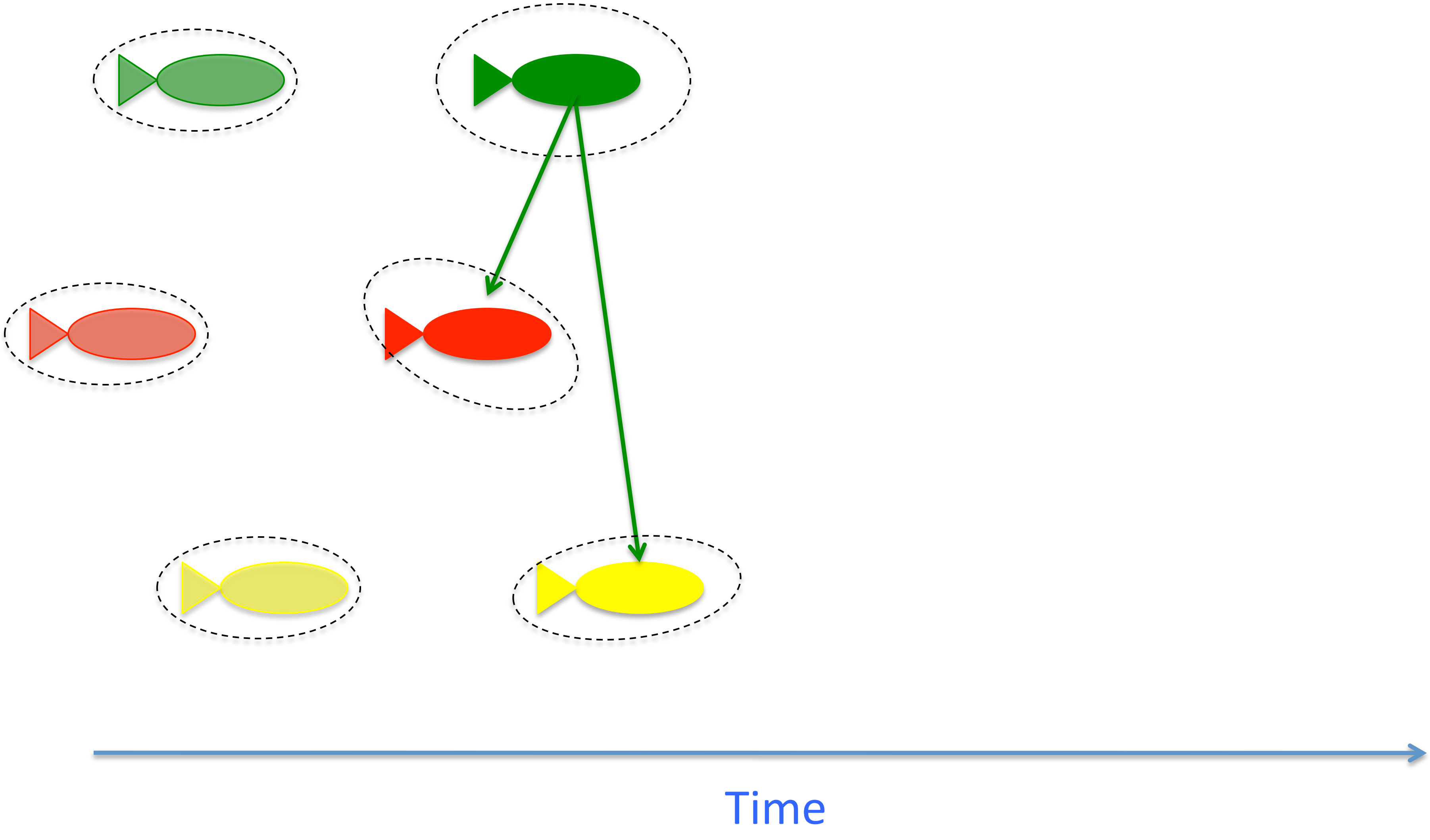

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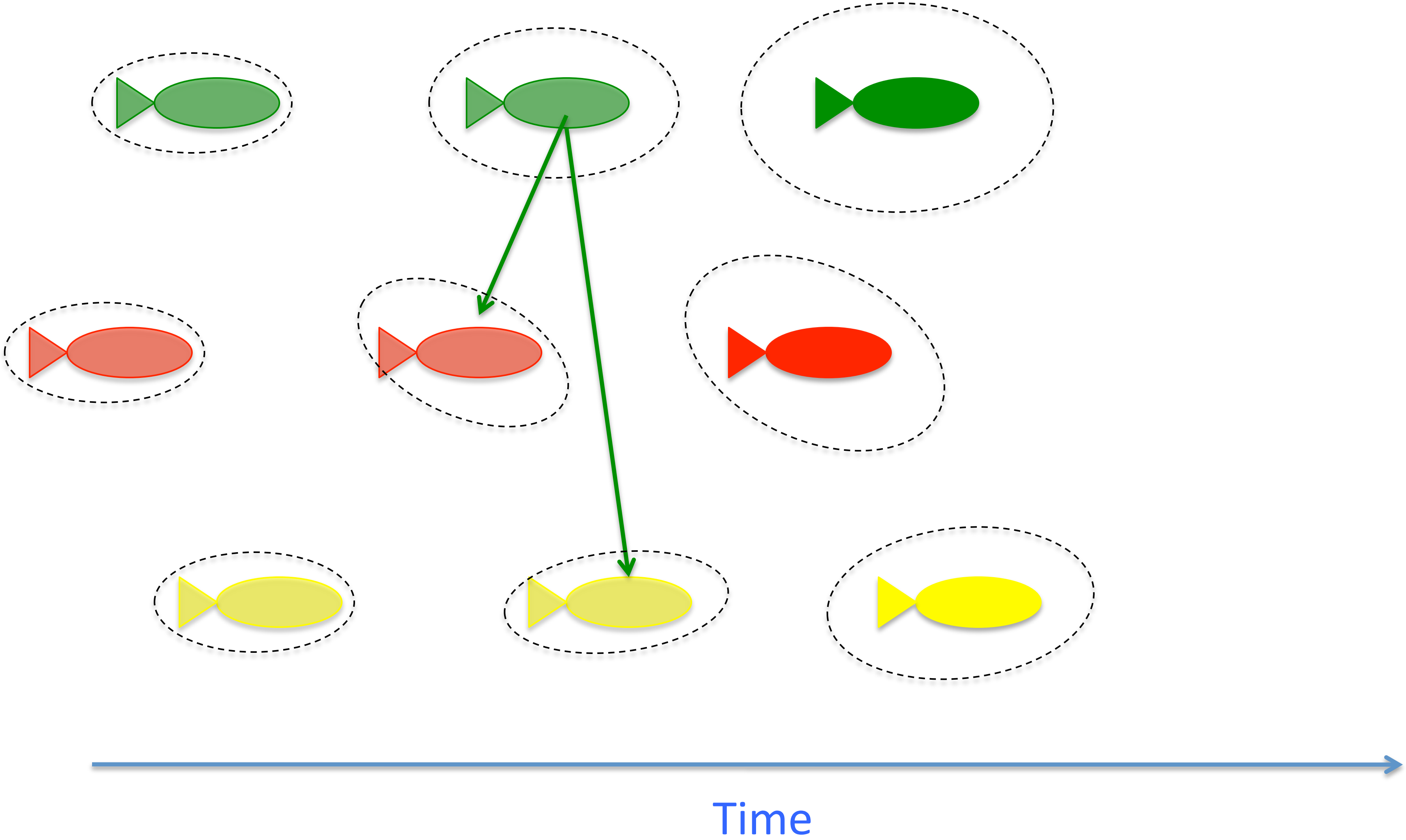

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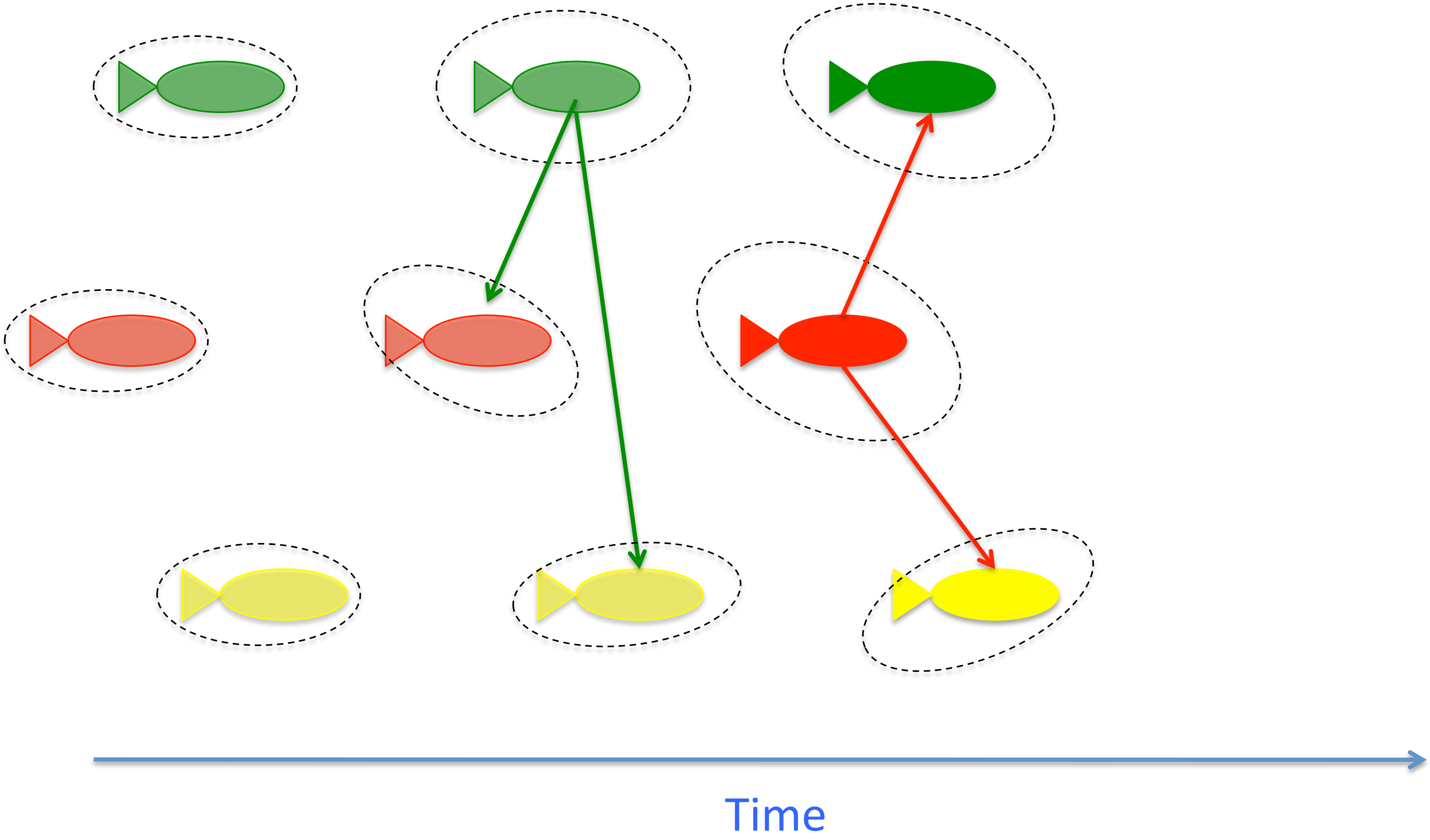

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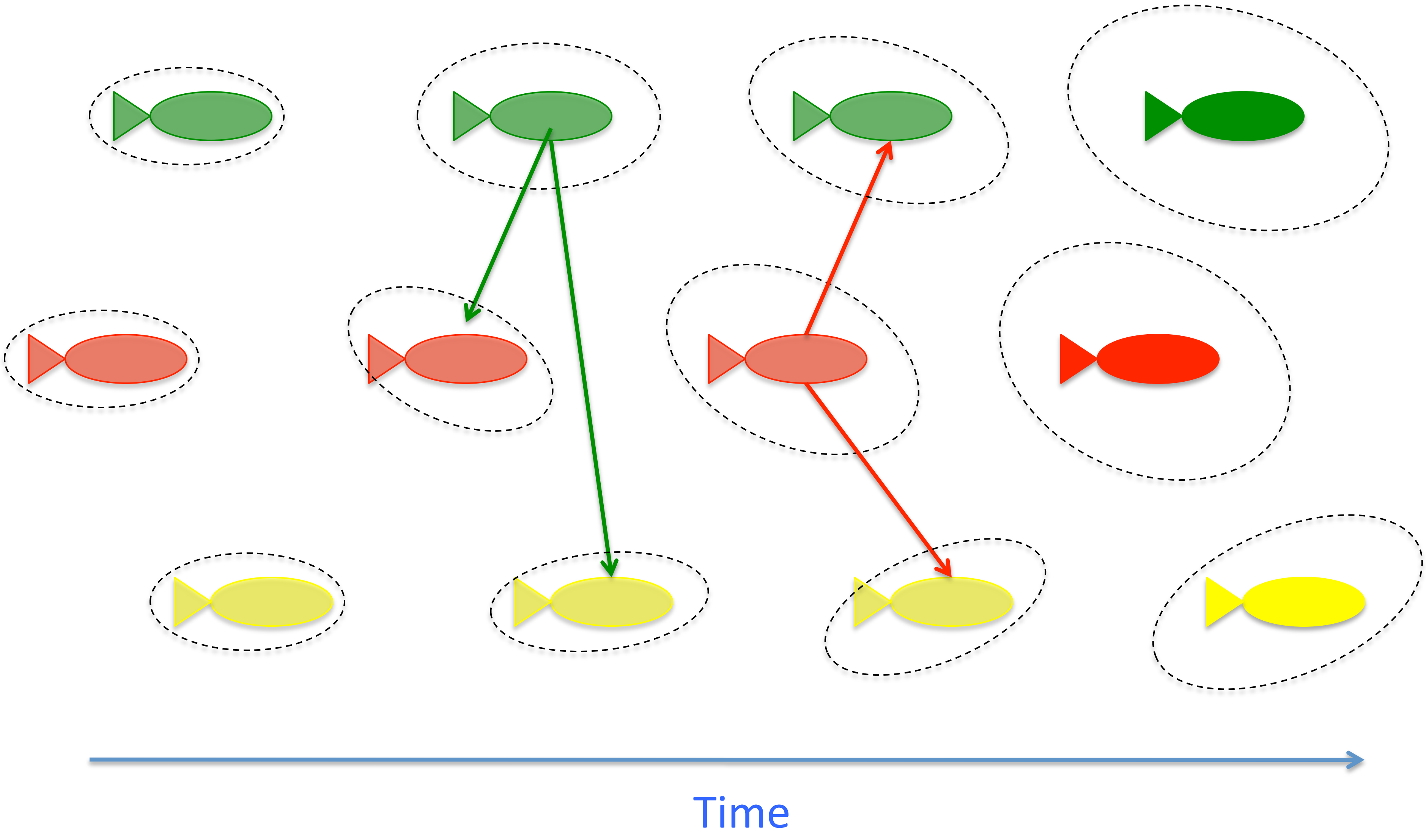

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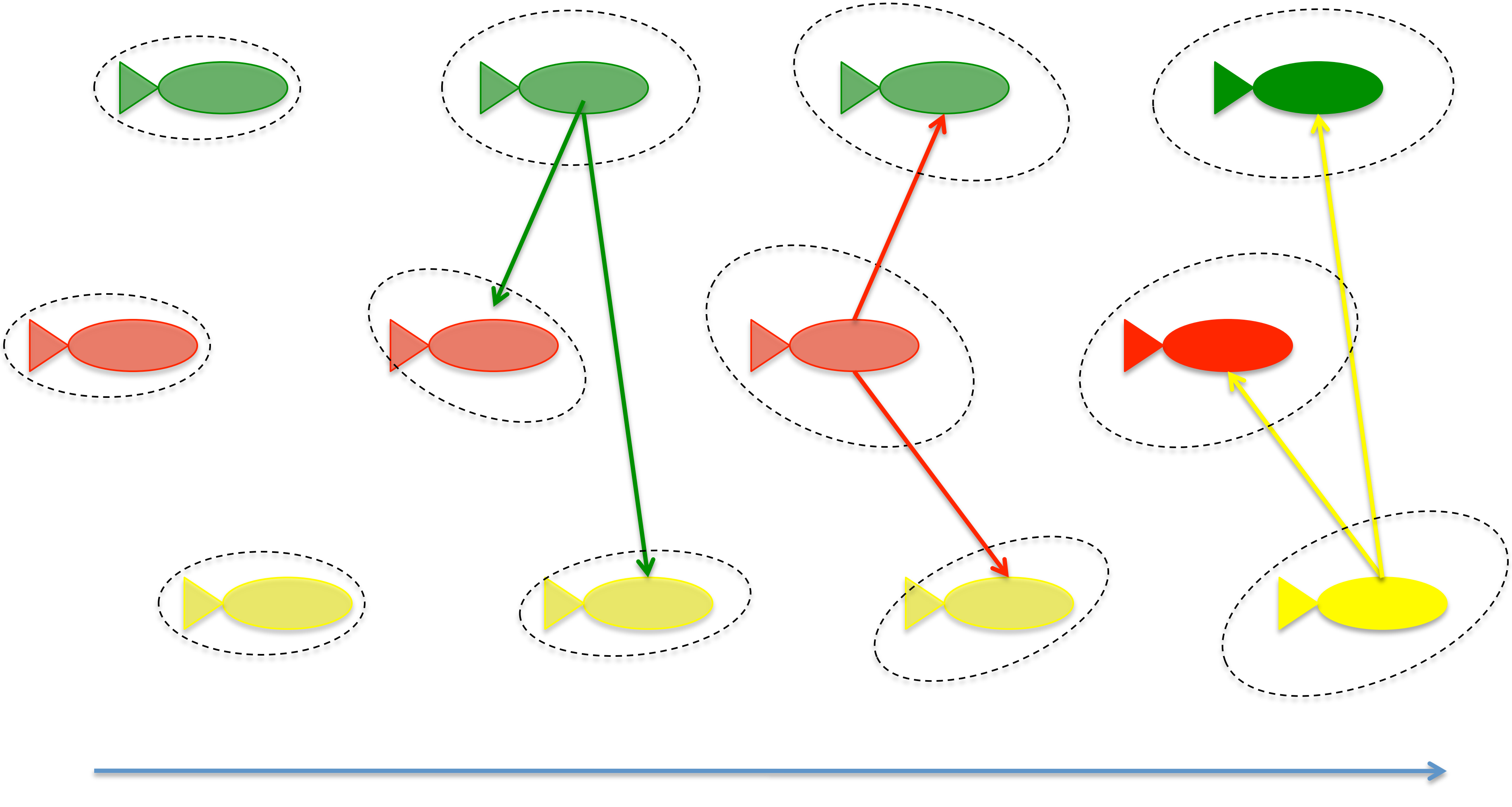
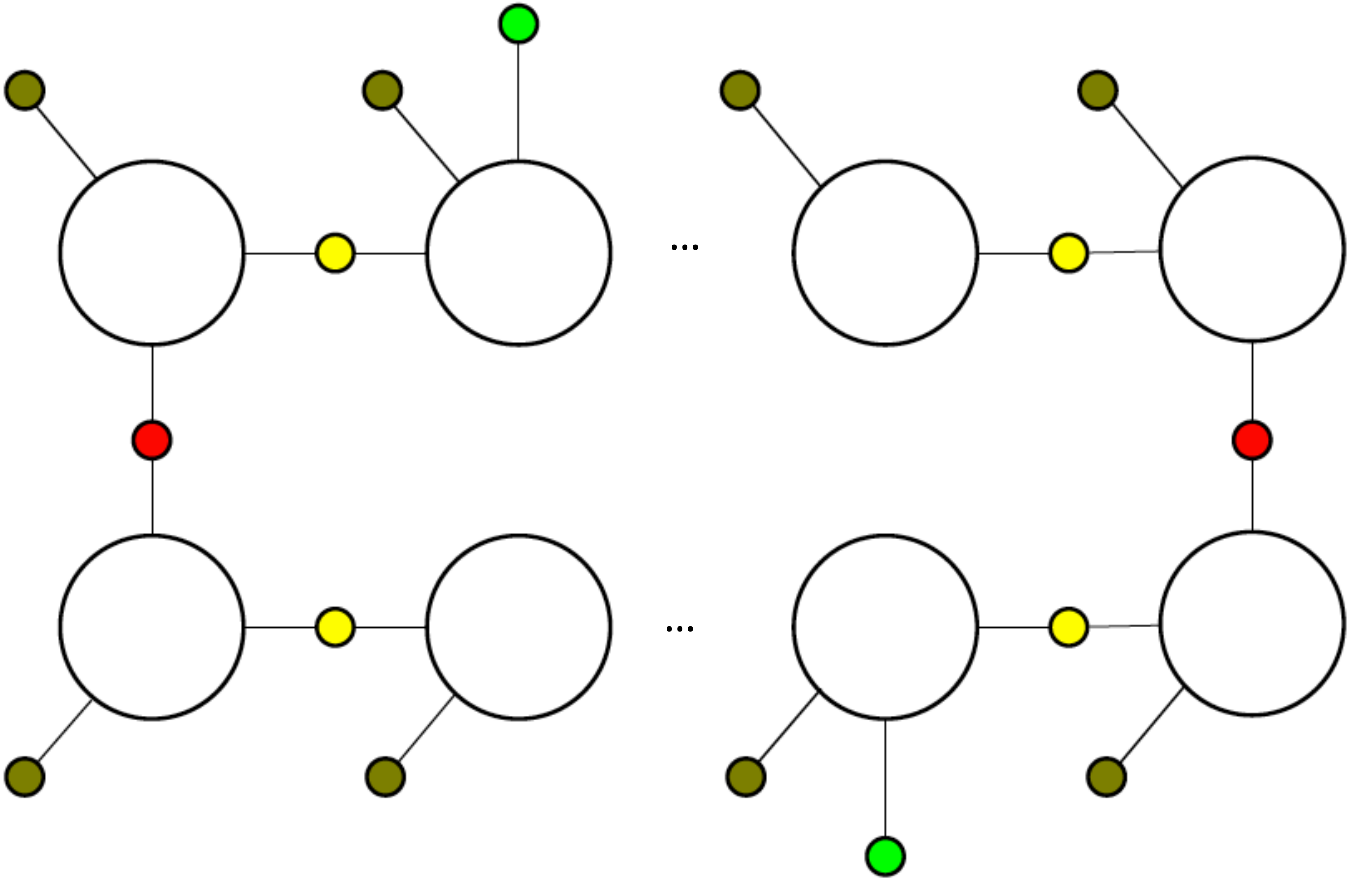
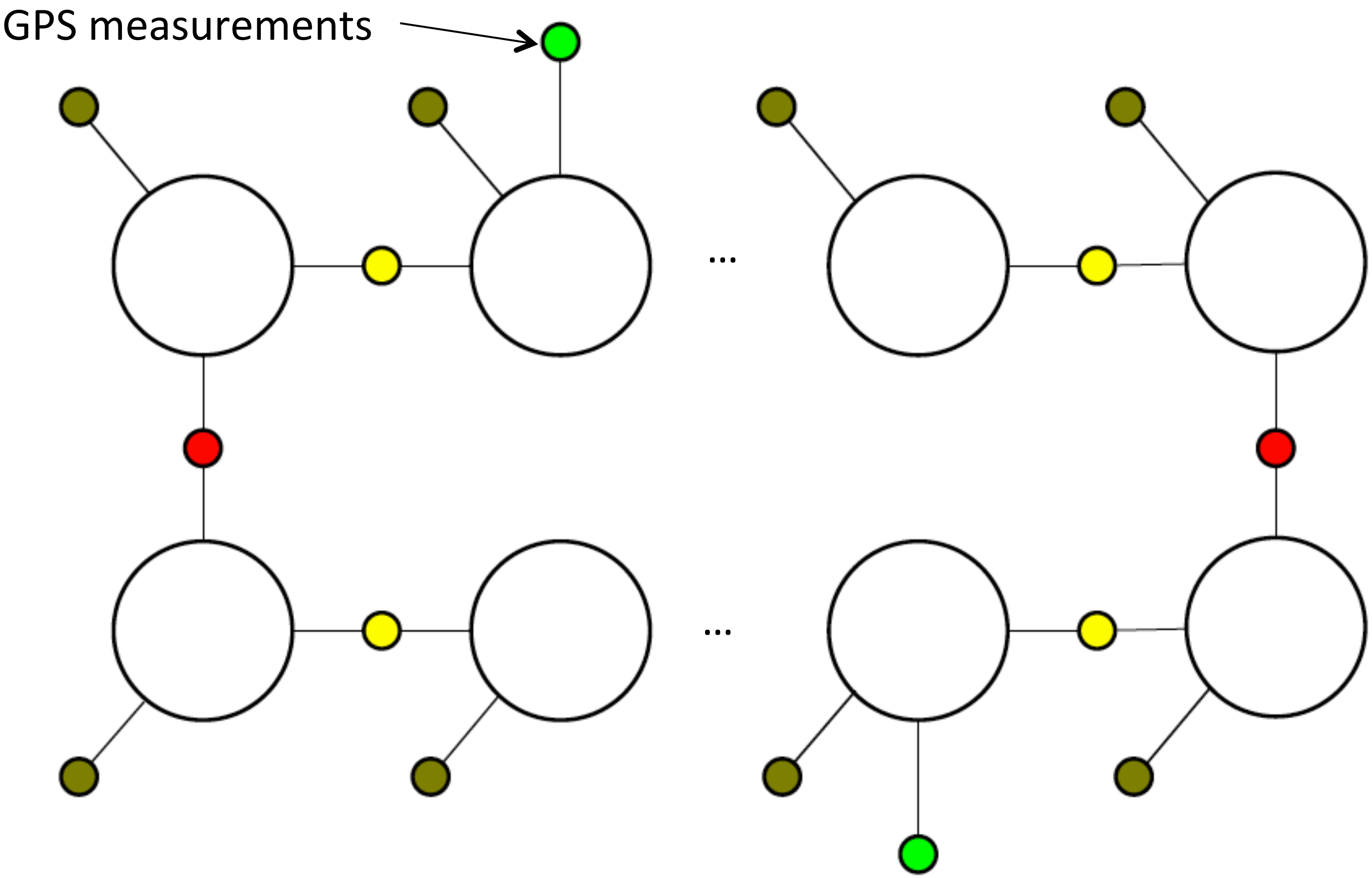


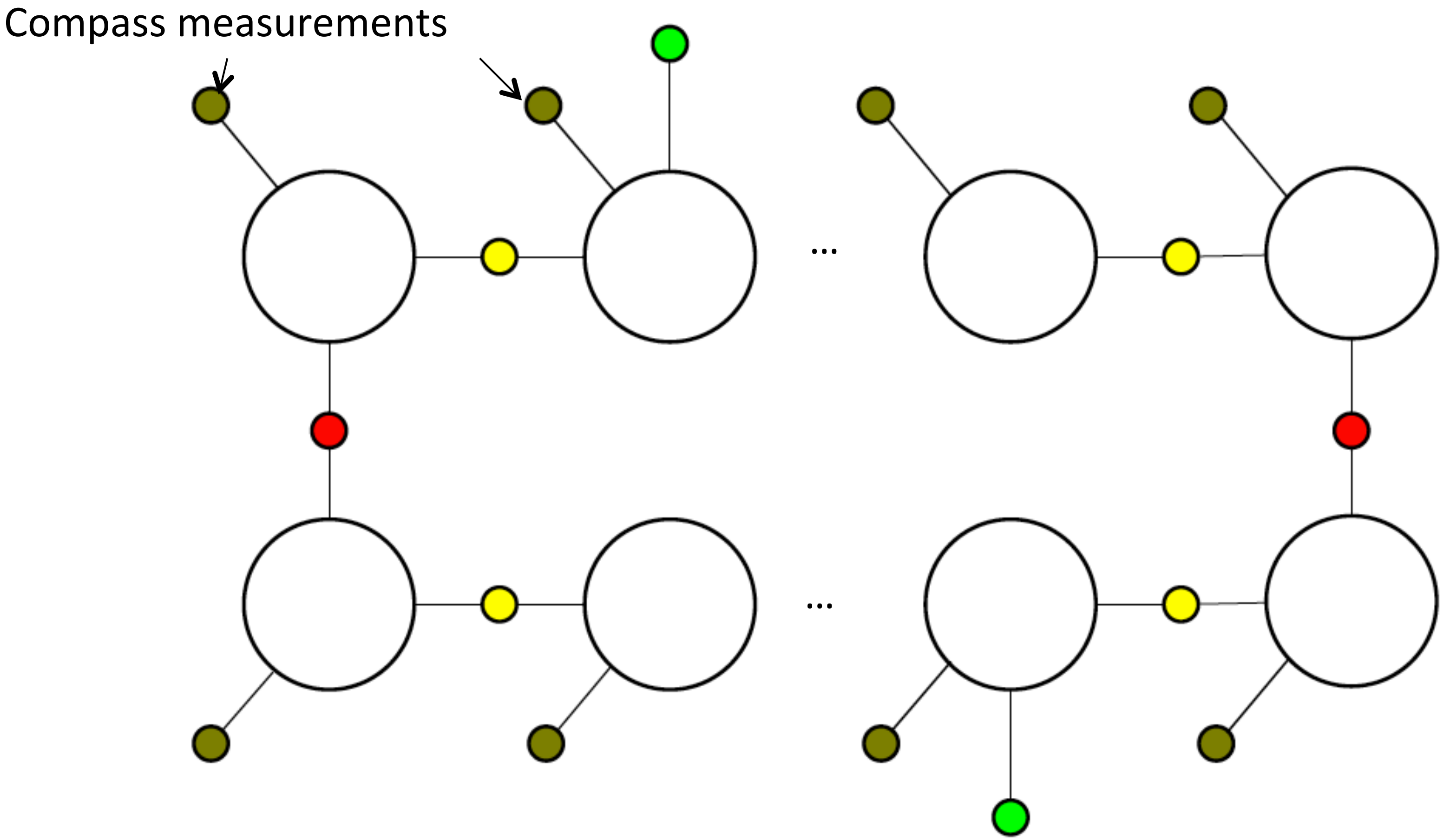
Centralized Multi-AUV Pose Graph



Centralized Multi-AUV Pose Graph



Centralized Multi-AUV Pose Graph



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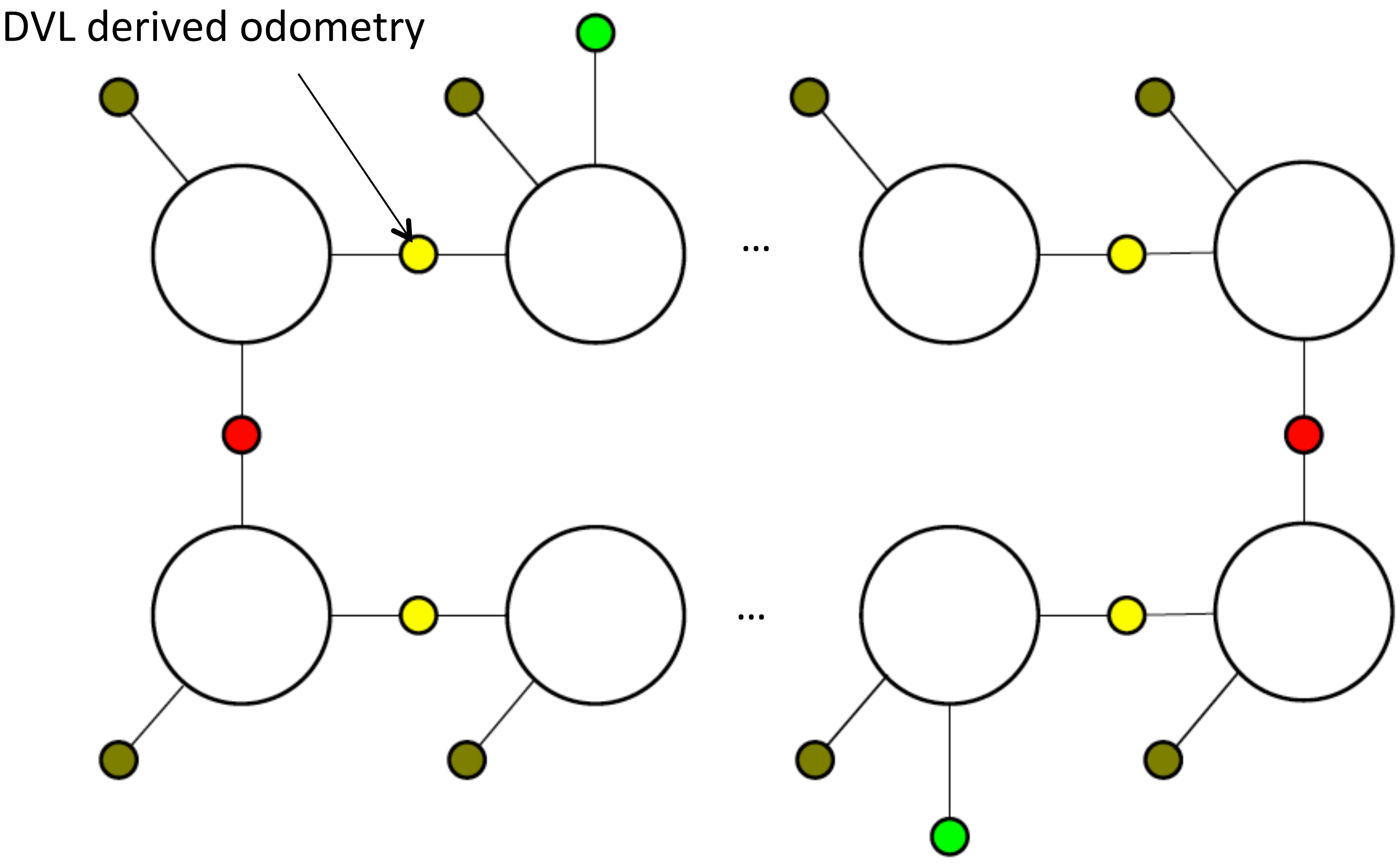

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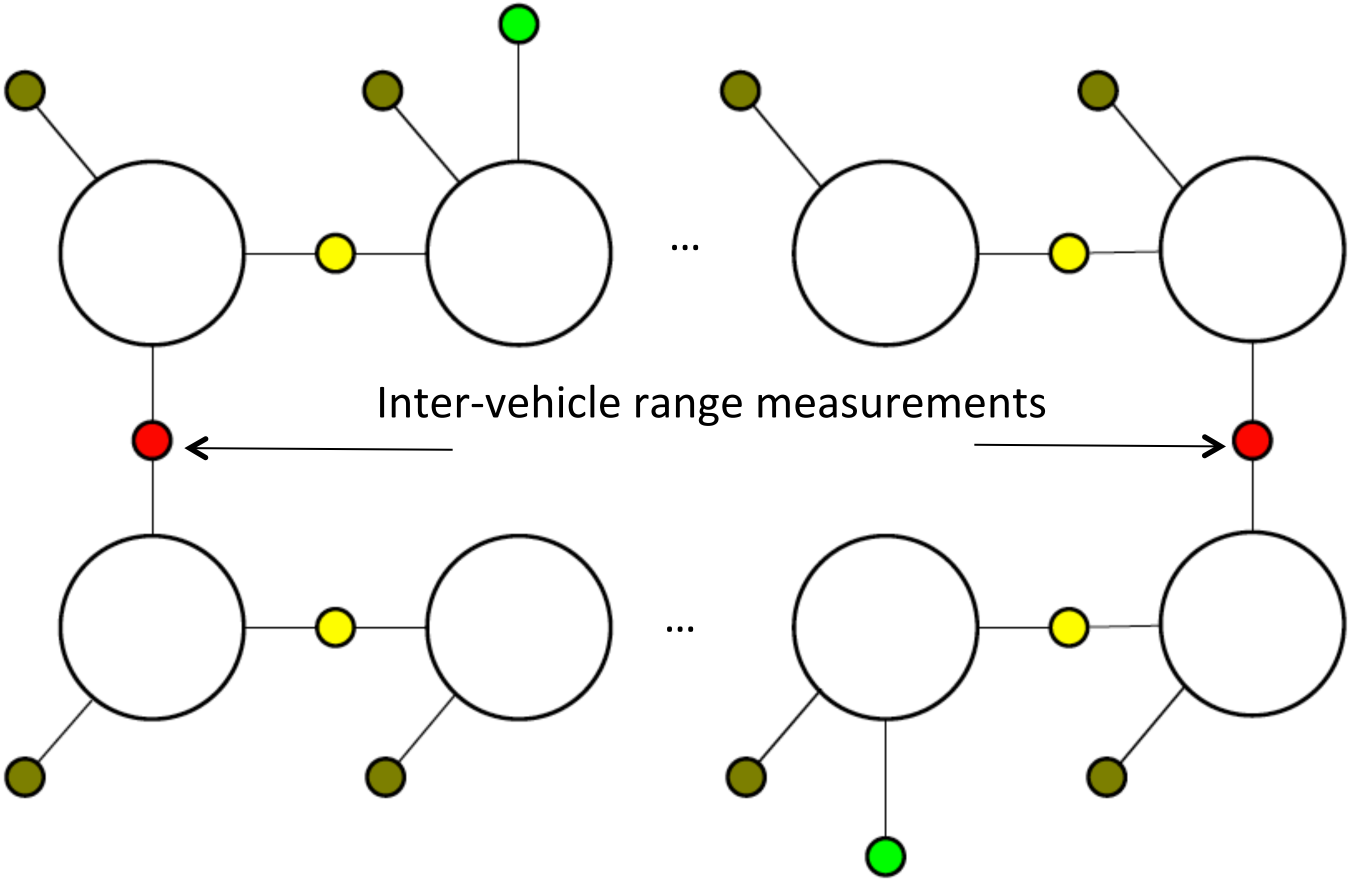
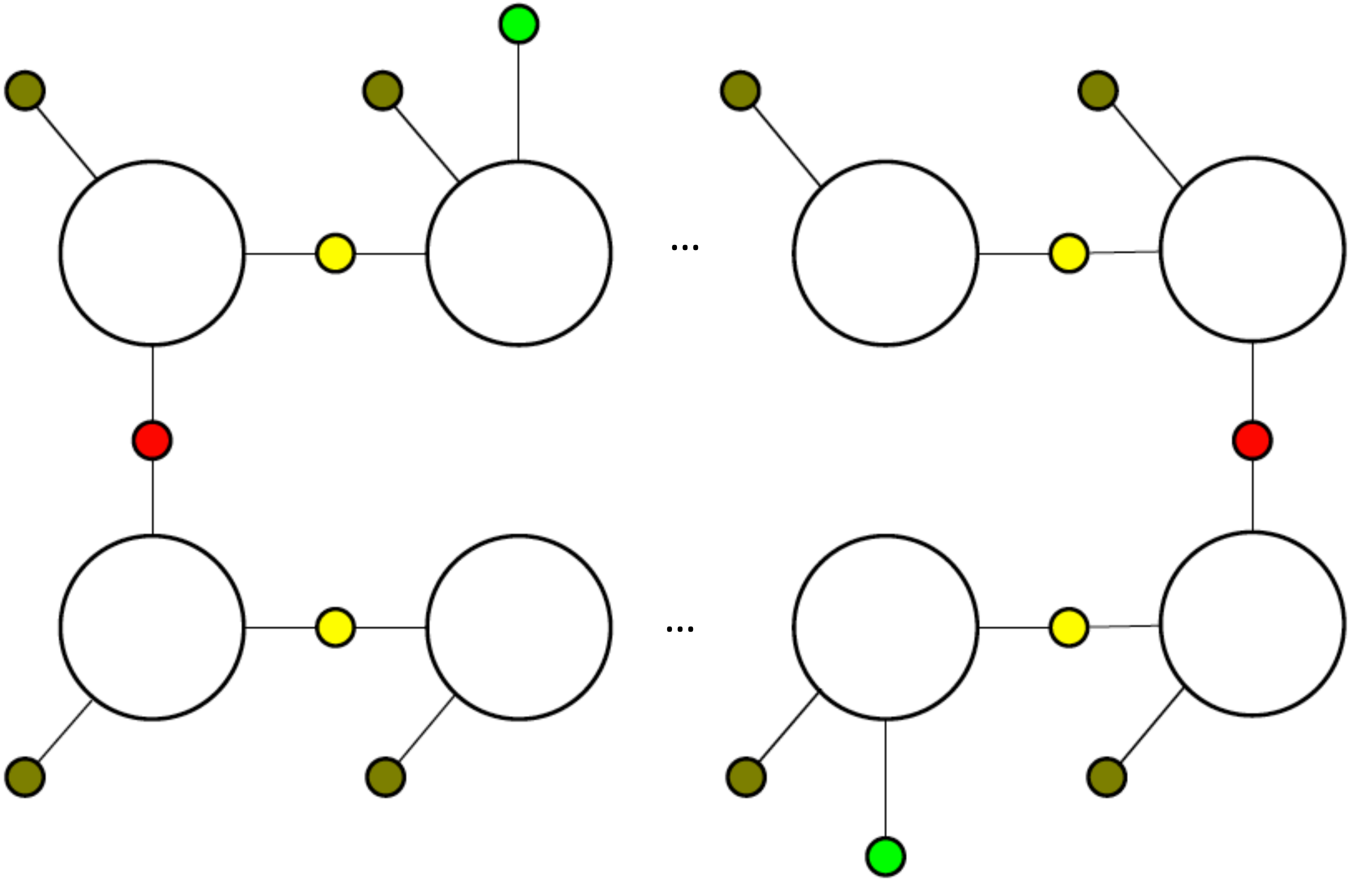


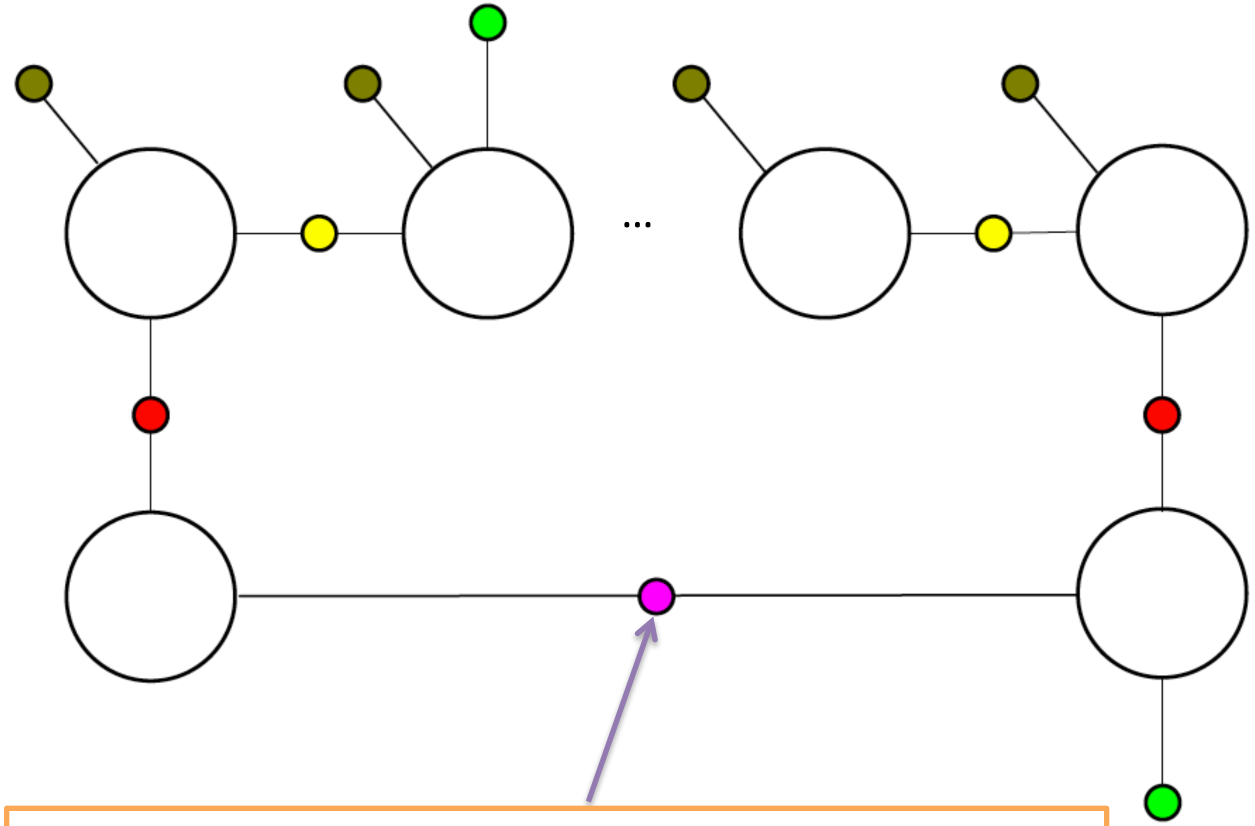
Inter-vehicle range measurements

Centralized Multi-AUV Pose Graph



Problem: Too much data to send through Acomms

Decentralized Multi-AUV Pose Graph



New factor connects other vehicle nodes at times of contact

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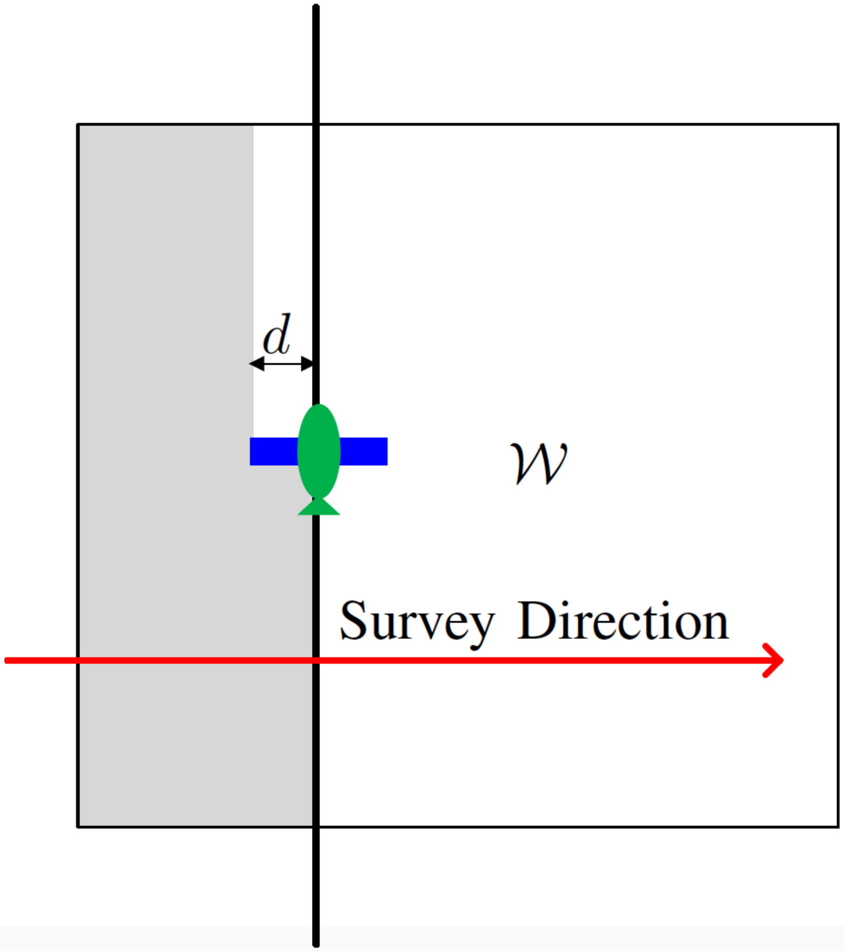
Online Adaptive Planning

- To close the gap between **desired** coverage and **actual** coverage we need an adaptive planner

Key Result: If the path tracking error is bounded and the state estimates are consistent – then we can guarantee that coverage will be achieved if possible **no matter how uncertain the state estimates are**.

Adaptive Coverage Path Planning



The track spacing *d* is updated in real-time based on most up-to-date trajectory and coverage estimate

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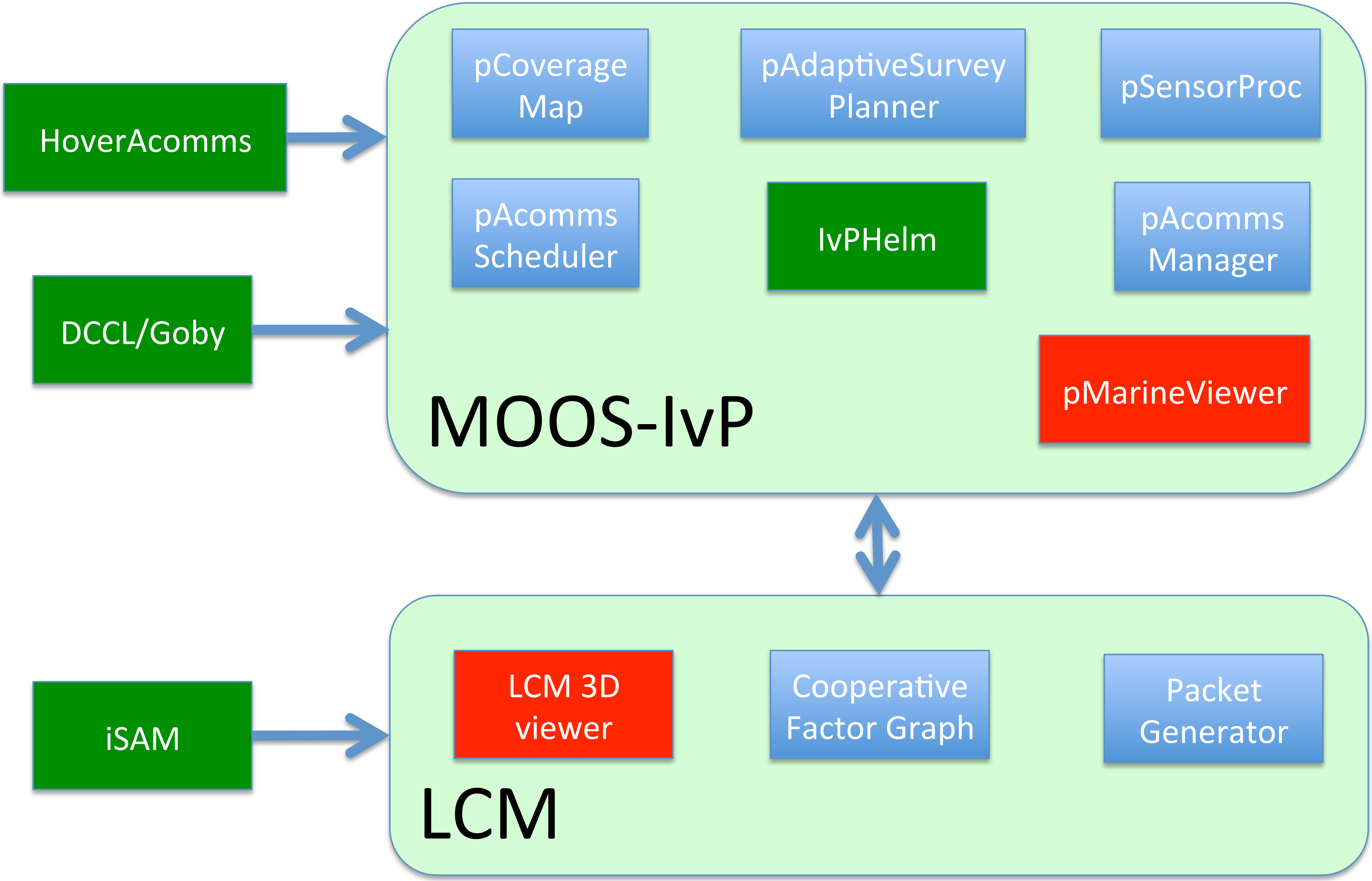
Software Setup



HoverAcomms

DCCL/Goby

iSAM

pCoverage Map

pAdaptiveSurvey Planner

pSensorProc

pAcomms Scheduler

IvPHelm

pAcomms Manager

pMarineViewer

MOOS-IvP

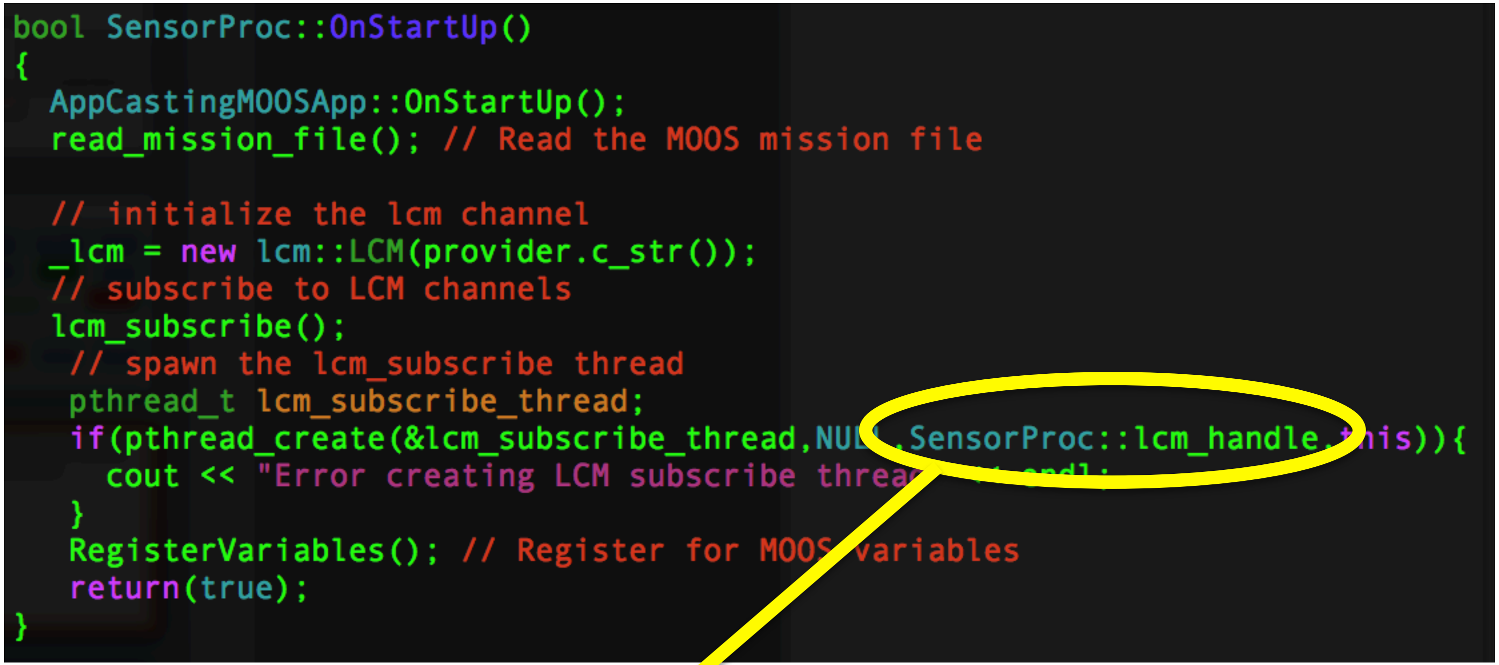
LCM 3D viewer

Cooperative Factor Graph

Packet Generator

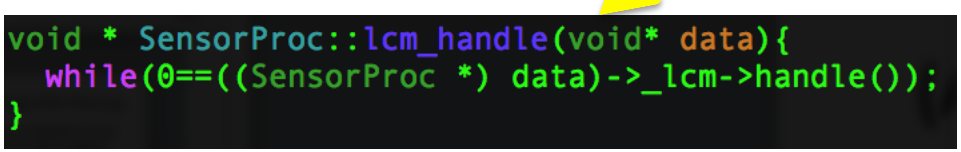
LCM

(Aside) You Don’t Have to Pick One Middleware



```
bool SensorProc::OnStartUp()
{
  AppCastingMOOSApp::OnStartUp();
  read_mission_file(); // Read the MOOS mission file

  // initialize the lcm channel
  _lcm = new lcm::LCM(provider.c_str());
  // subscribe to LCM channels
  lcm_subscribe();
   // spawn the lcm_subscribe thread
   pthread_t lcm_subscribe_thread;
   if(pthread_create(&lcm_subscribe_thread,NULL,SensorProc::lcm_handle,this)){
     cout << "Error creating LCM subscribe thread" << endl;
   }
   RegisterVariables(); // Register for MOOS variables
   return(true);
}
```



```
void * SensorProc::lcm_handle(void* data){
  while(0==((SensorProc *) data)->_lcm->handle());
}
```

Hardware

IVER2 @ DRDC Atlantic

Hover kayak on the Charles River

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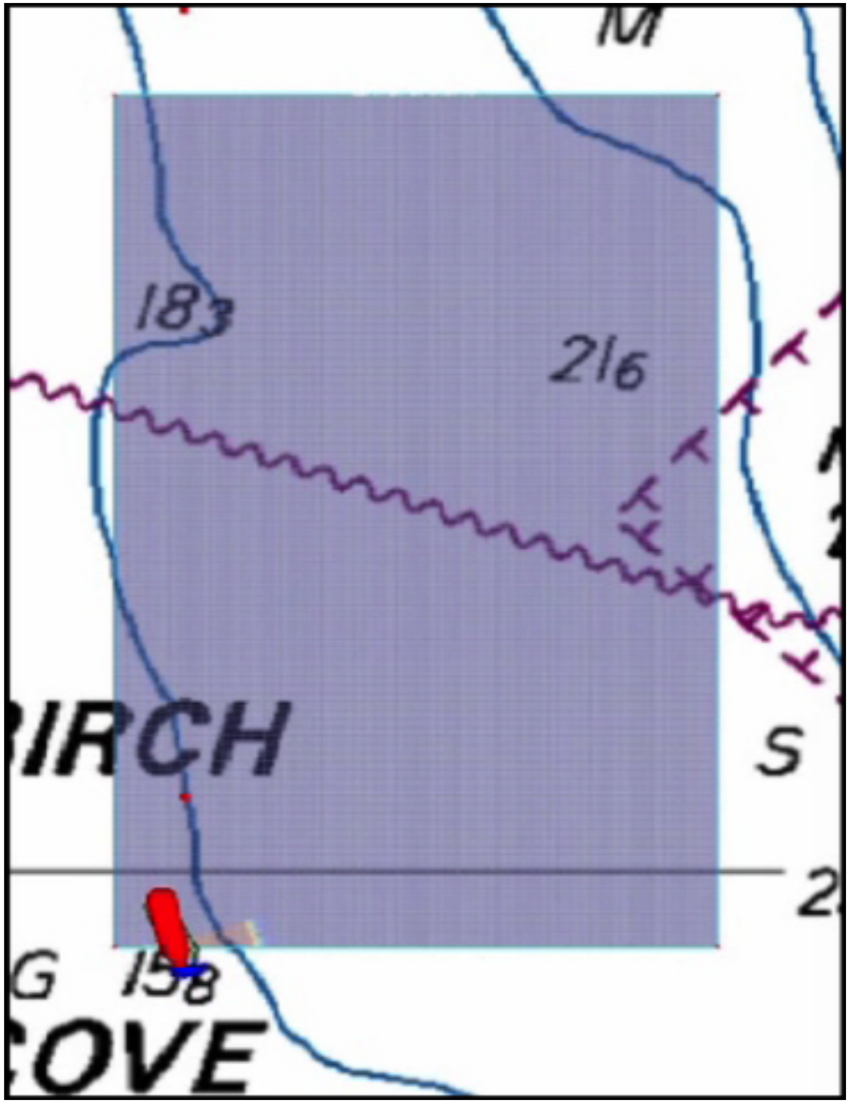
Results – Single Vehicle



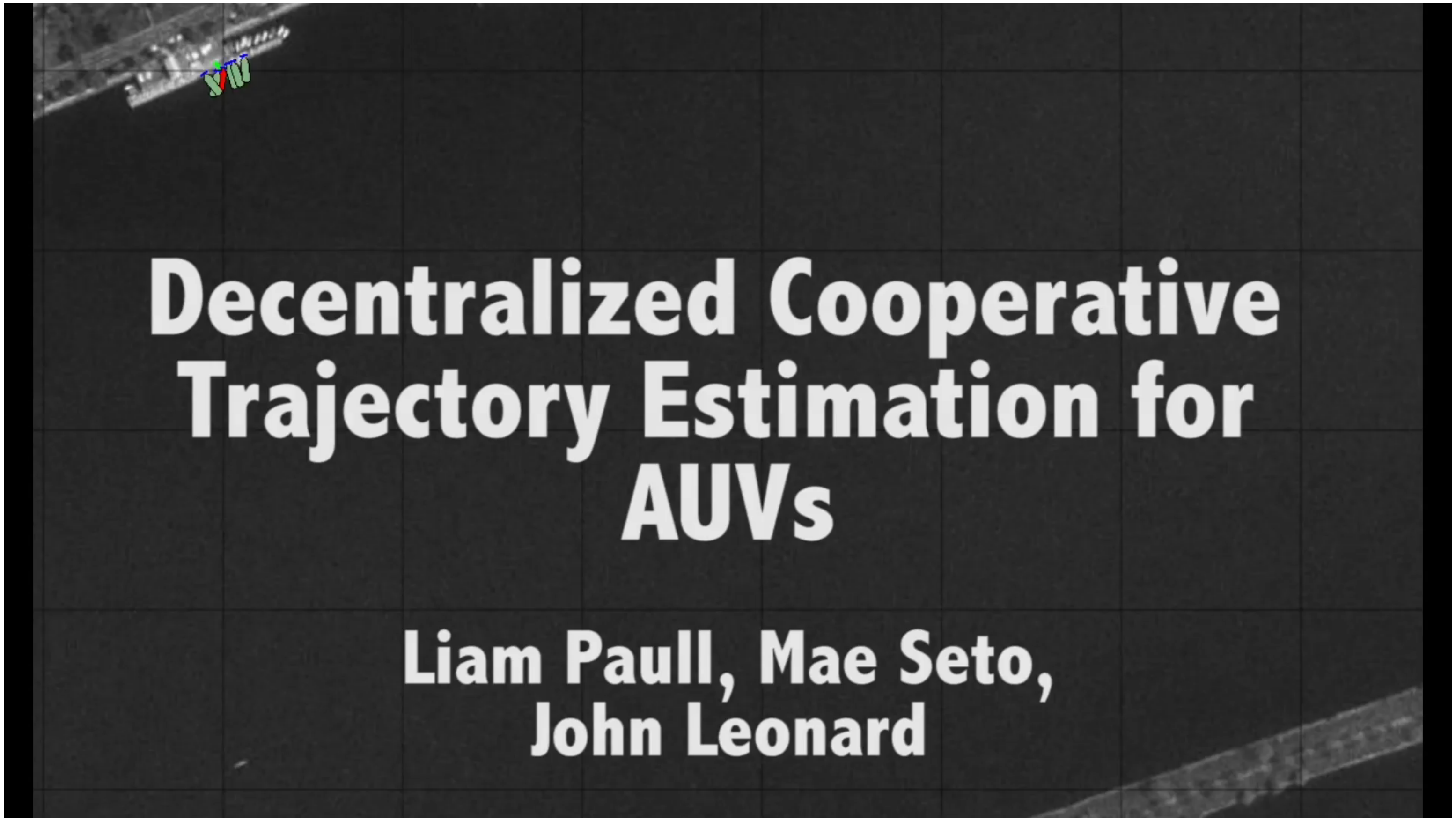
Green AUV: Estimated

Red AUV: Actual

- Coverage map shows actual coverage
- GPS updates received at end of track
- Tracks are regenerated after each GPS update

[1] Paull, Seto and Li. Area coverage that accounts for pose uncertainty with an AUV surveying application. ICRA 2014.

Results – Decentralized Trajectory Estimation

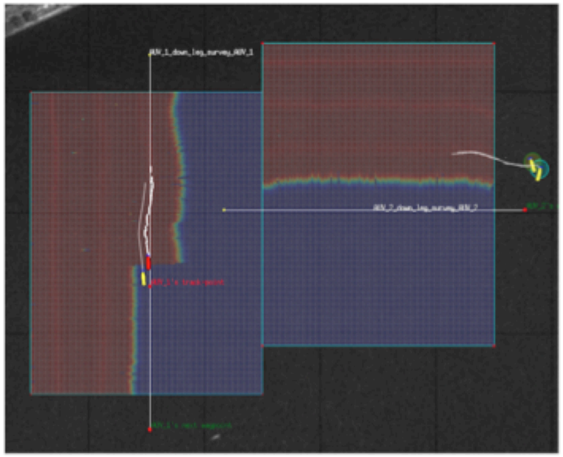


Decentralized Cooperative Trajectory Estimation for AUVs

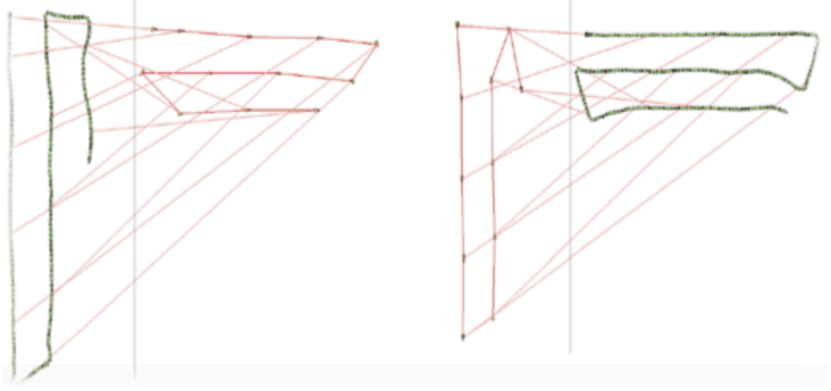
Liam Paull, Mae Seto, John Leonard

[2] Paull, Seto, and Leonard. Decentralized Cooperative Trajectory Estimation for Autonomous Underwater Vehicles. IROS 2014.

Simulation Results - Cooperative

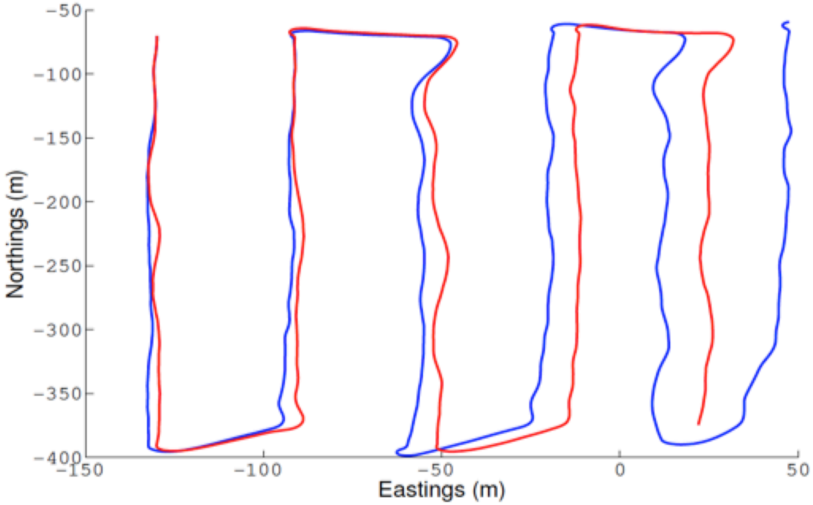


Actual and **estimated** robot positions and areas to be covered



Decentralized trajectory estimates

Paths for **cooperative** and **non-cooperative** adaptive survey paths →
(Cooperative – 1757m, Non-cooperative 2113m)



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Come and see cooperative trajectory estimation with accoms on the kayaks at the demo tomorrow