Multi-Robot Adaptive Navigation

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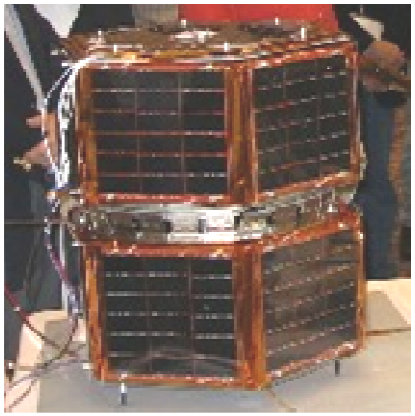
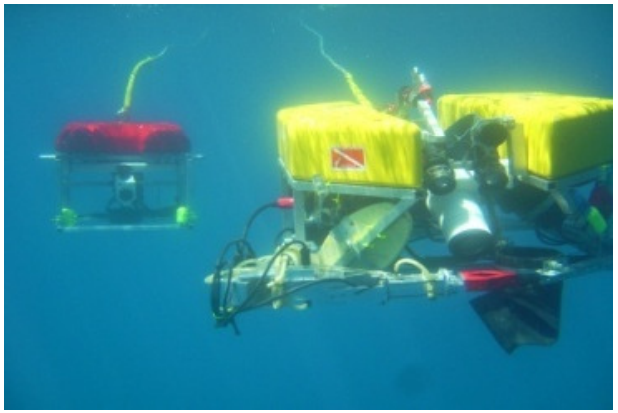
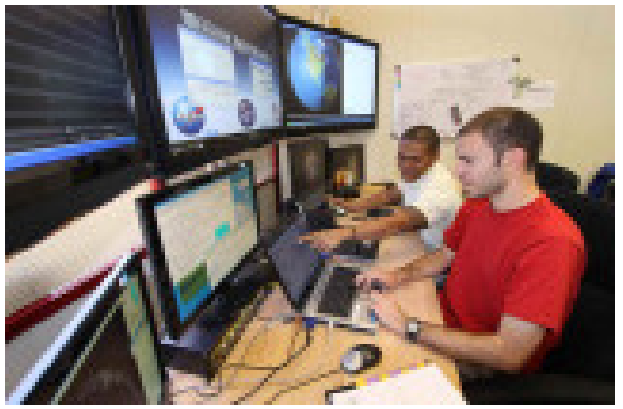
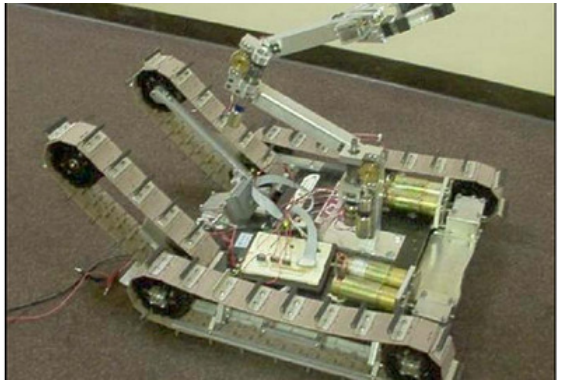
School of Engineering, Santa Clara University

Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling

Robotic Systems Laboratory

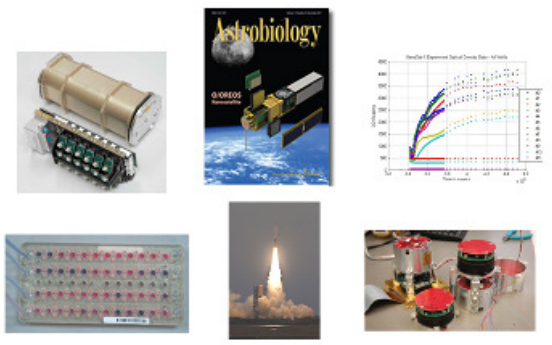
- We design & operate advanced robotic systems and control technology for land, sea, air, and space

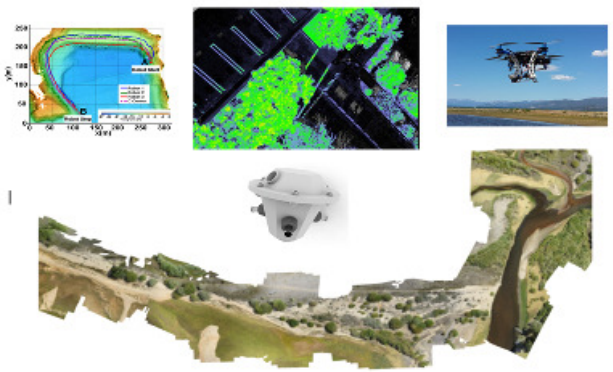
Robotic Systems Laboratory

- We conduct field operations to provide advanced engineering services to professional partners

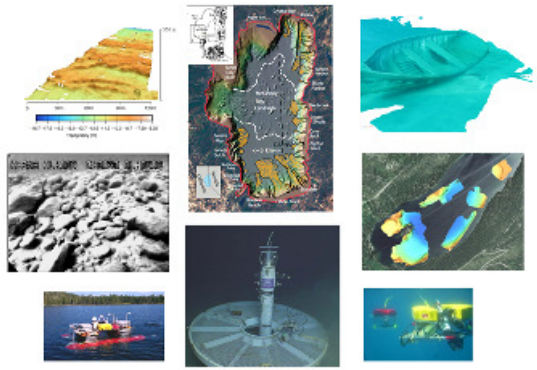
Fundamental Biology



Environmental Monitoring



Marine Geology, Biochemistry & Archaeology



Robotic Systems Laboratory

- We conduct field operations to provide advanced engineering services to professional partners

Corporations

Universities

Government Agencies

Non-Profits

Robotic Systems Laboratory

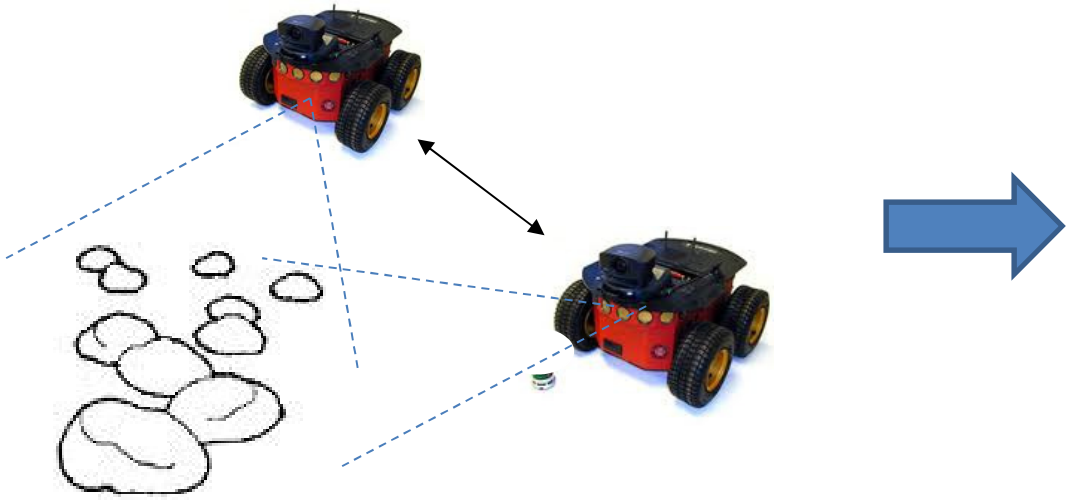
- We do this with interdisciplinary student teams, from freshman to PhD, to provide world-class education and research experiences

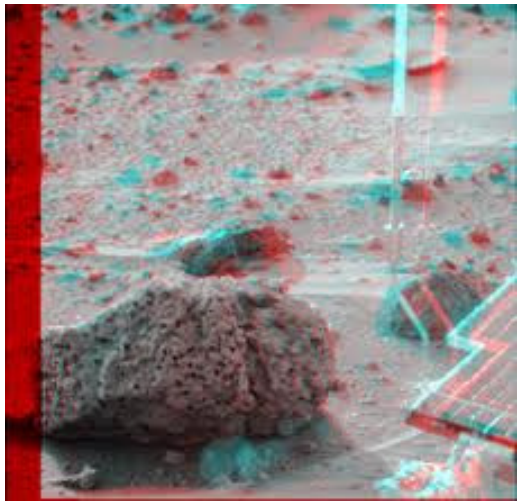
Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling

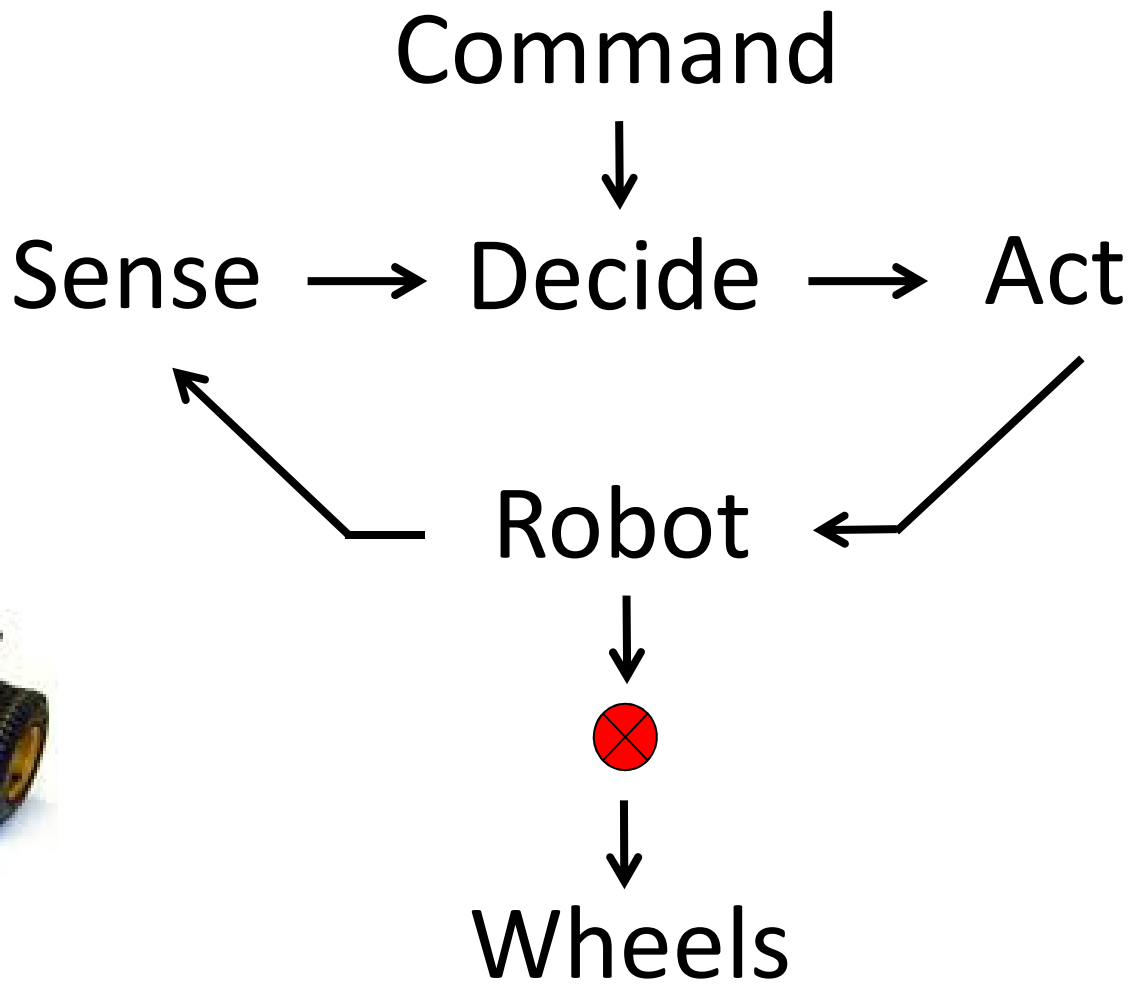
Multi-Robot Systems

- Our specific interest is in applications requiring:
  - Highly reactive to the environment
  - Tight interaction between robots
  - Relative spatial/position control





Multi-Robot Control Approach

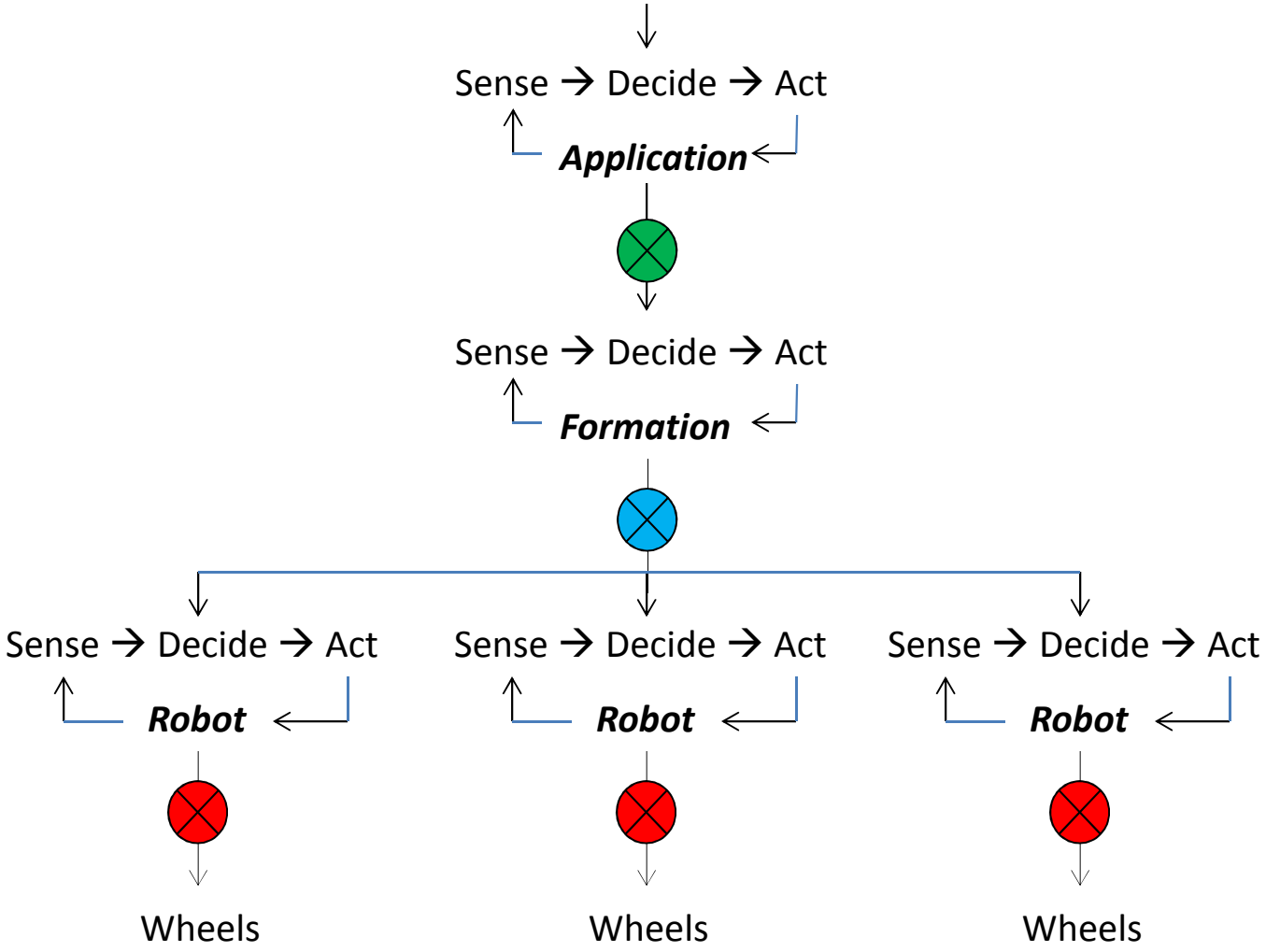


Multi-Robot Control Approach

Optimize Application …

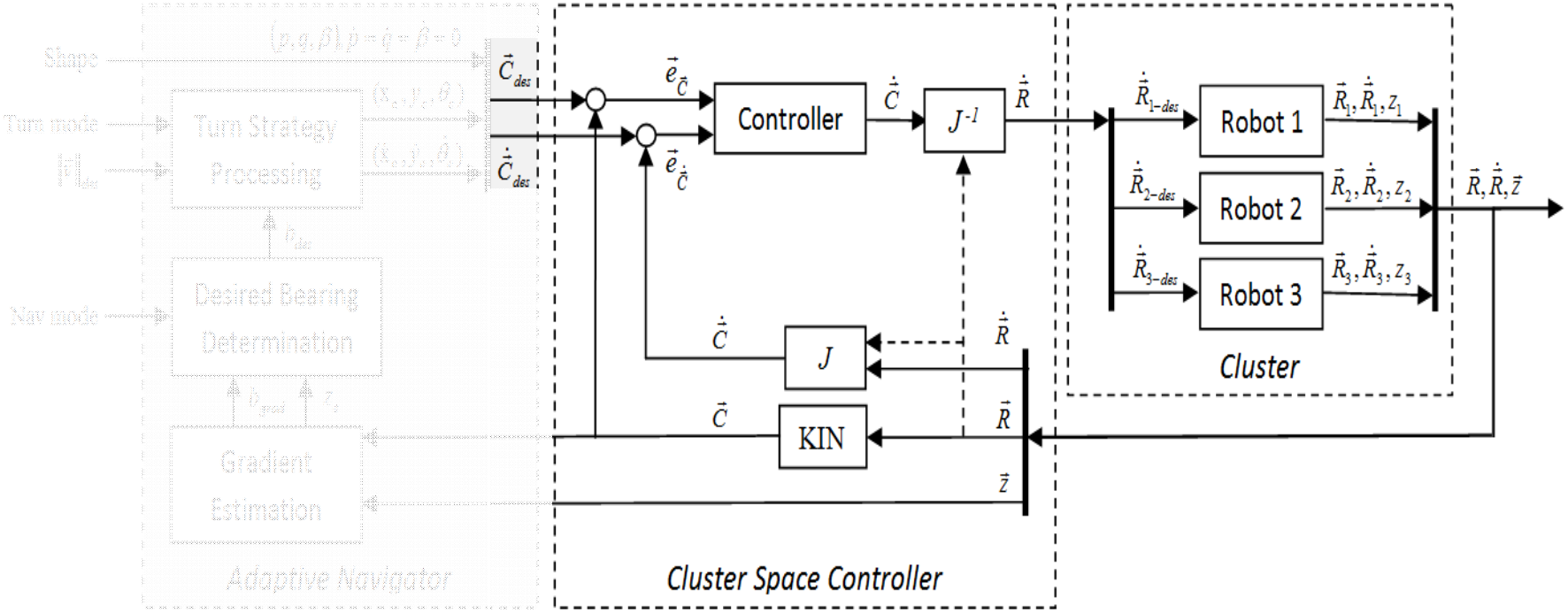
Vary Formation …

Operate Robots …



Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient



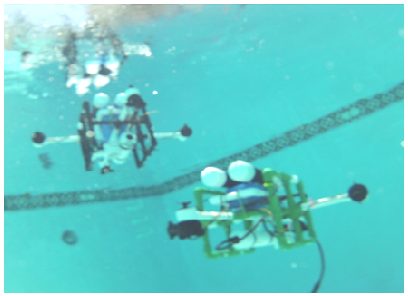
Multi-Robot Systems

- Potential applications
  - Physically escort / guard objects
  - Implement sparse antenna arrays
  - Track the location of objects
  - Transport “large” objects
  - Efficiently find features in an environmental field

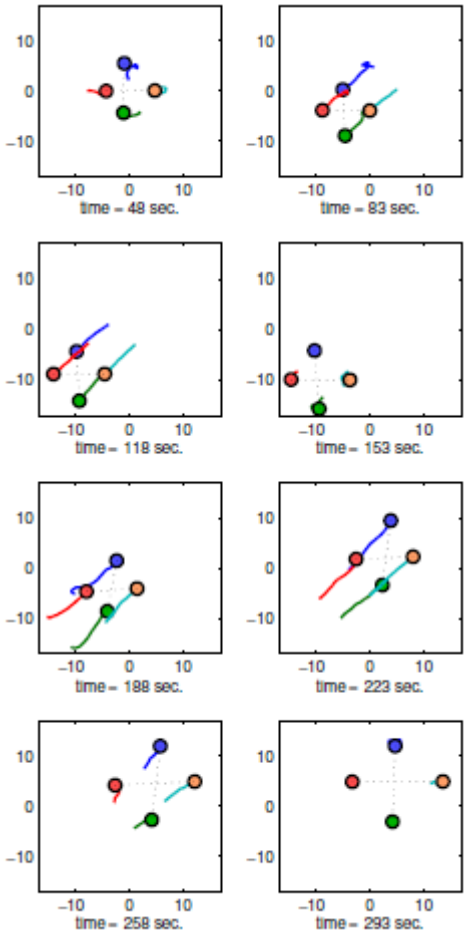
- Multi-robot are in their infancy
  - Perhaps they are a bad idea….
  - Hopefully, it is simply because it is hard to do!

Formation Control Results

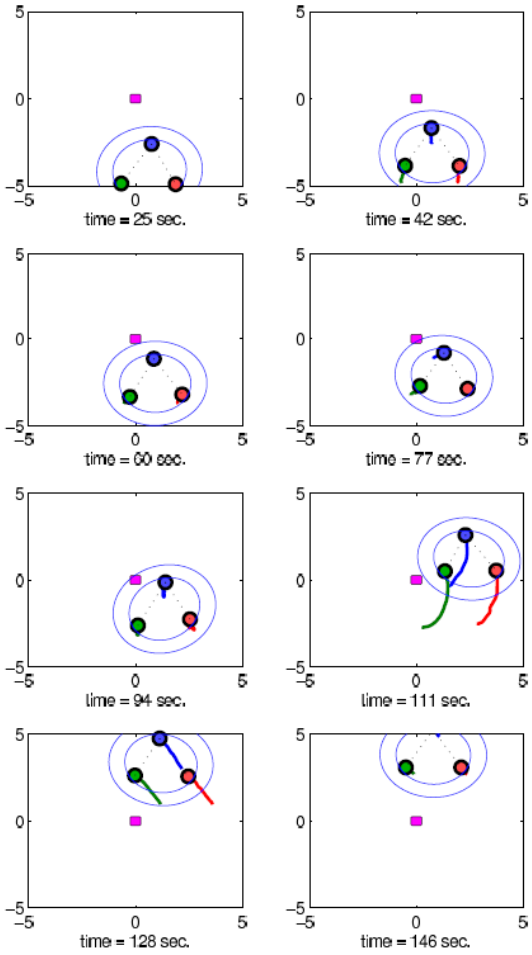
Testbeds



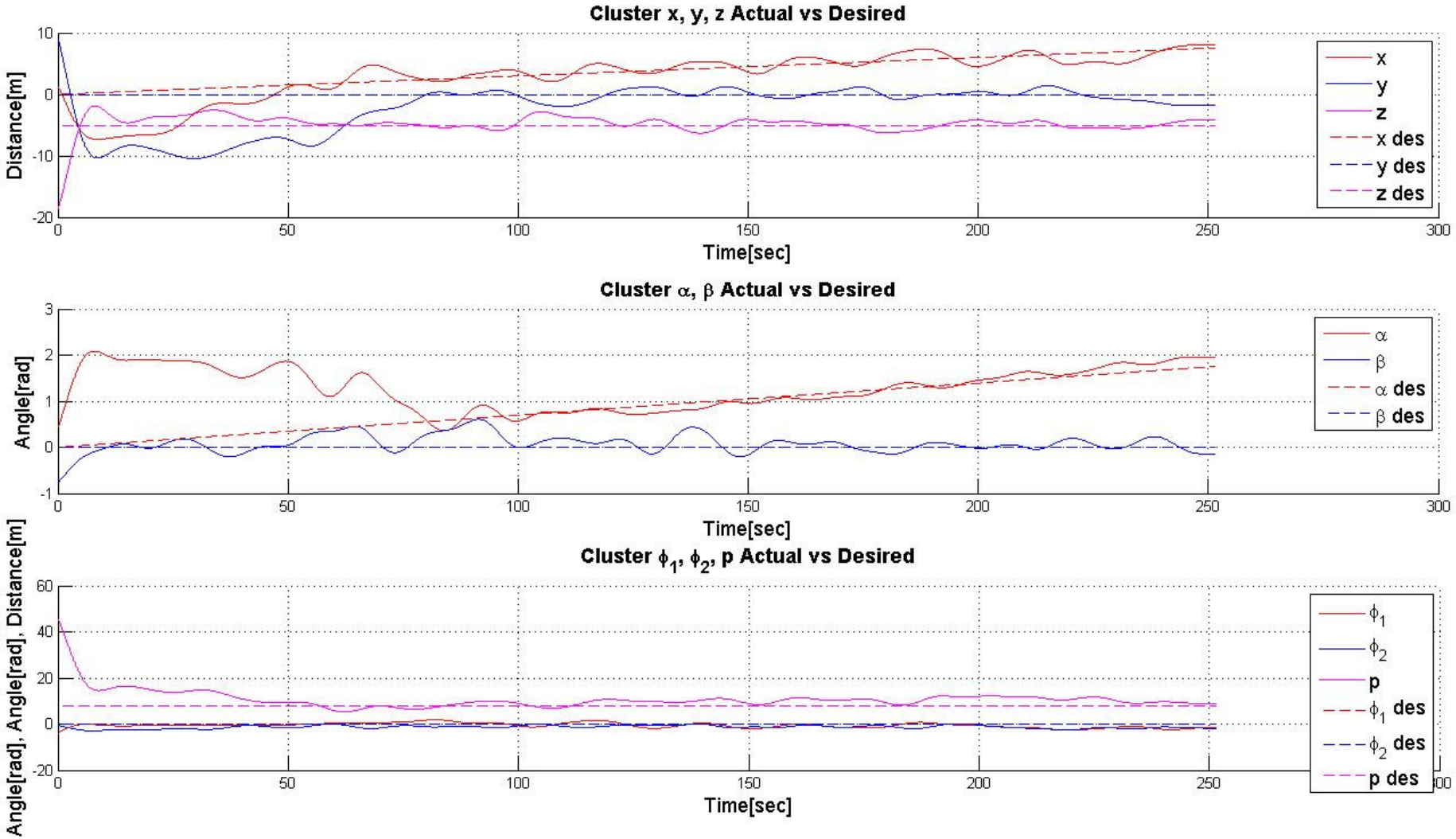
Basic Maneuvering



Obstacle avoidance

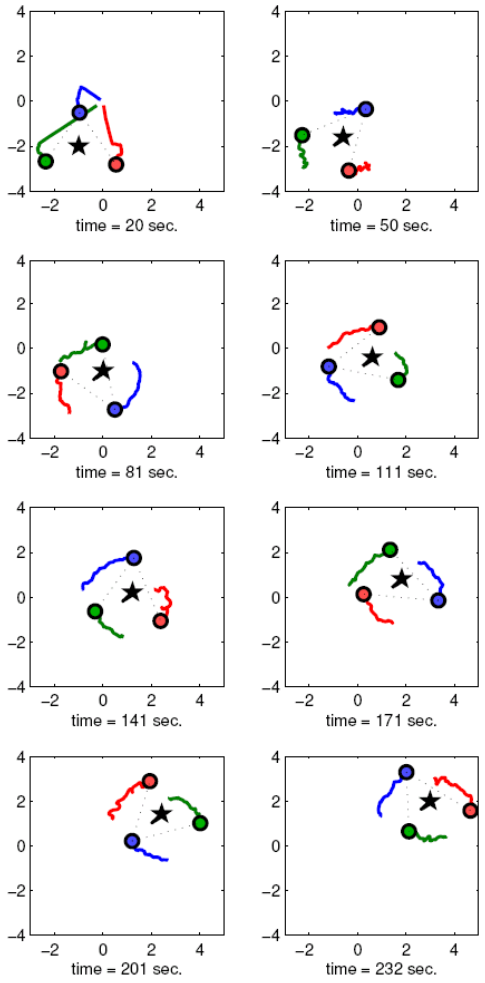


Formation Control Results

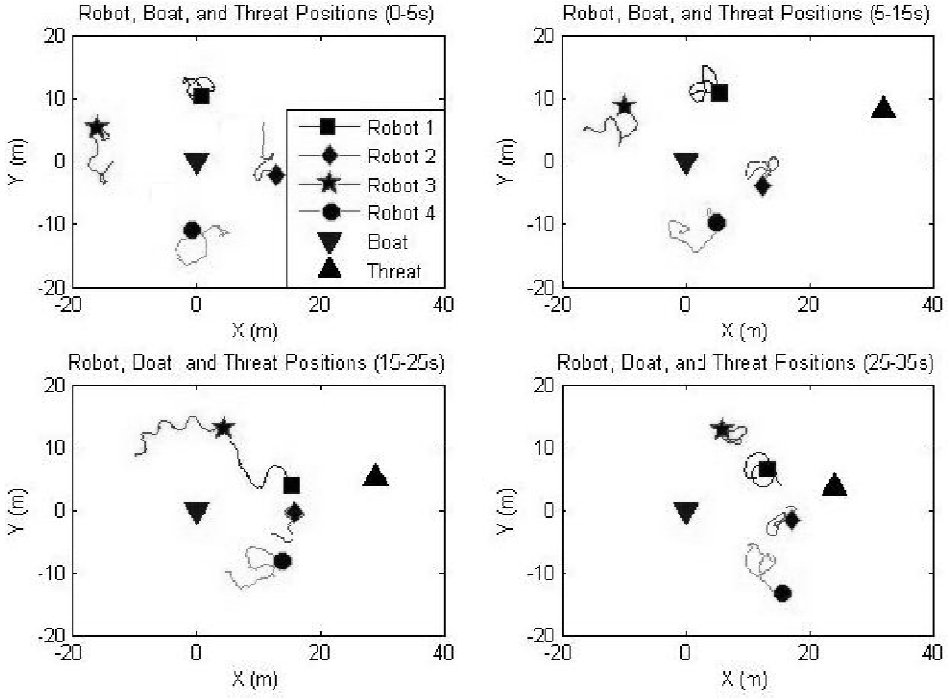


Patrolling / Guarding

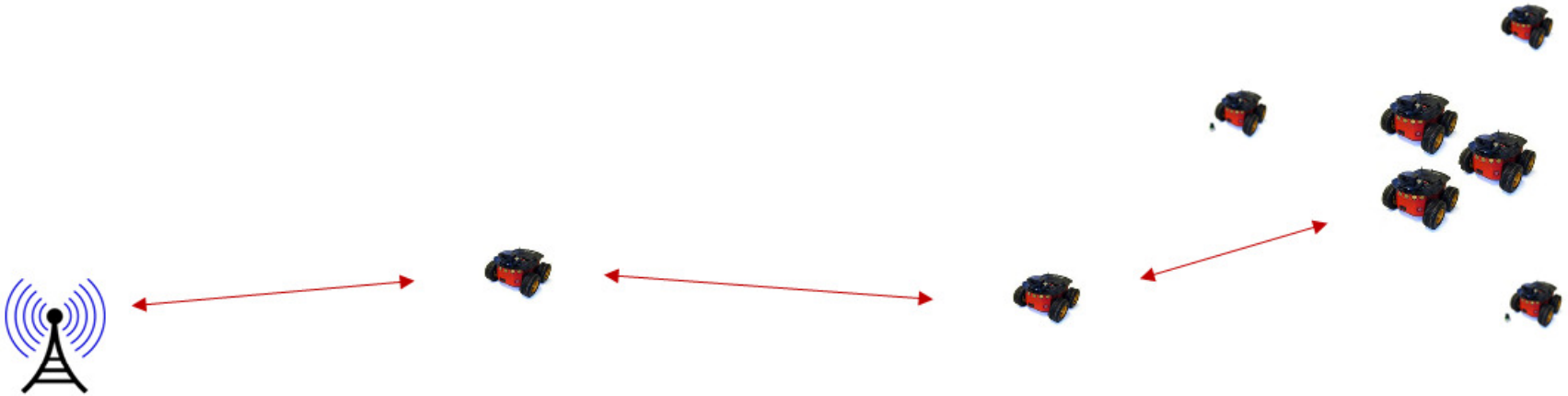
Rotating Escort



Dynamic Guarding



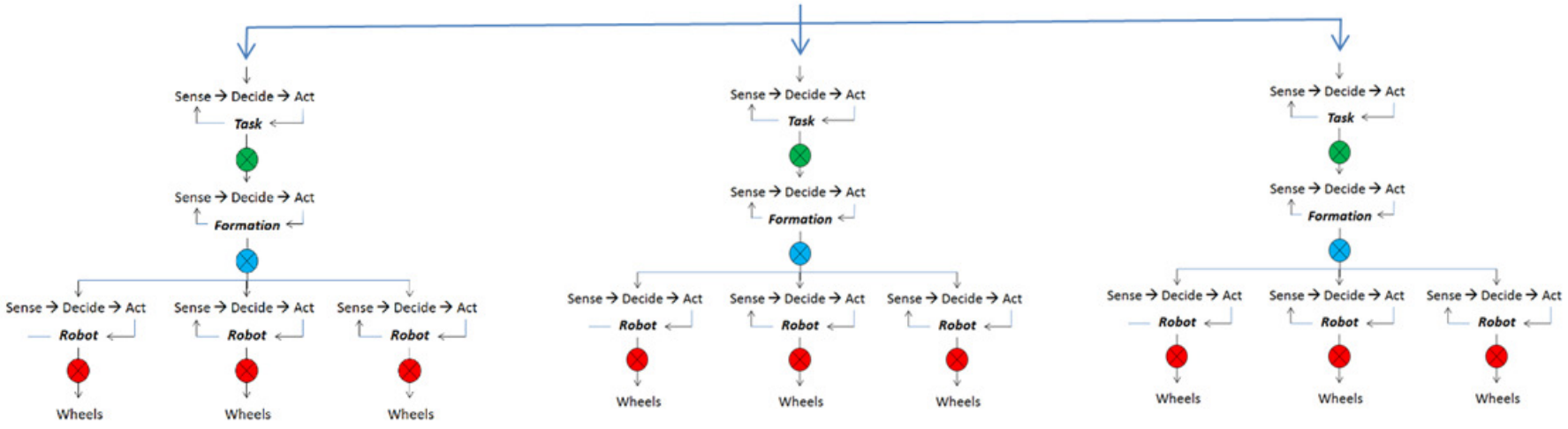
Multi-Robot Control Approach



Cooperative Mission Management

Task coordination

Resource allocation

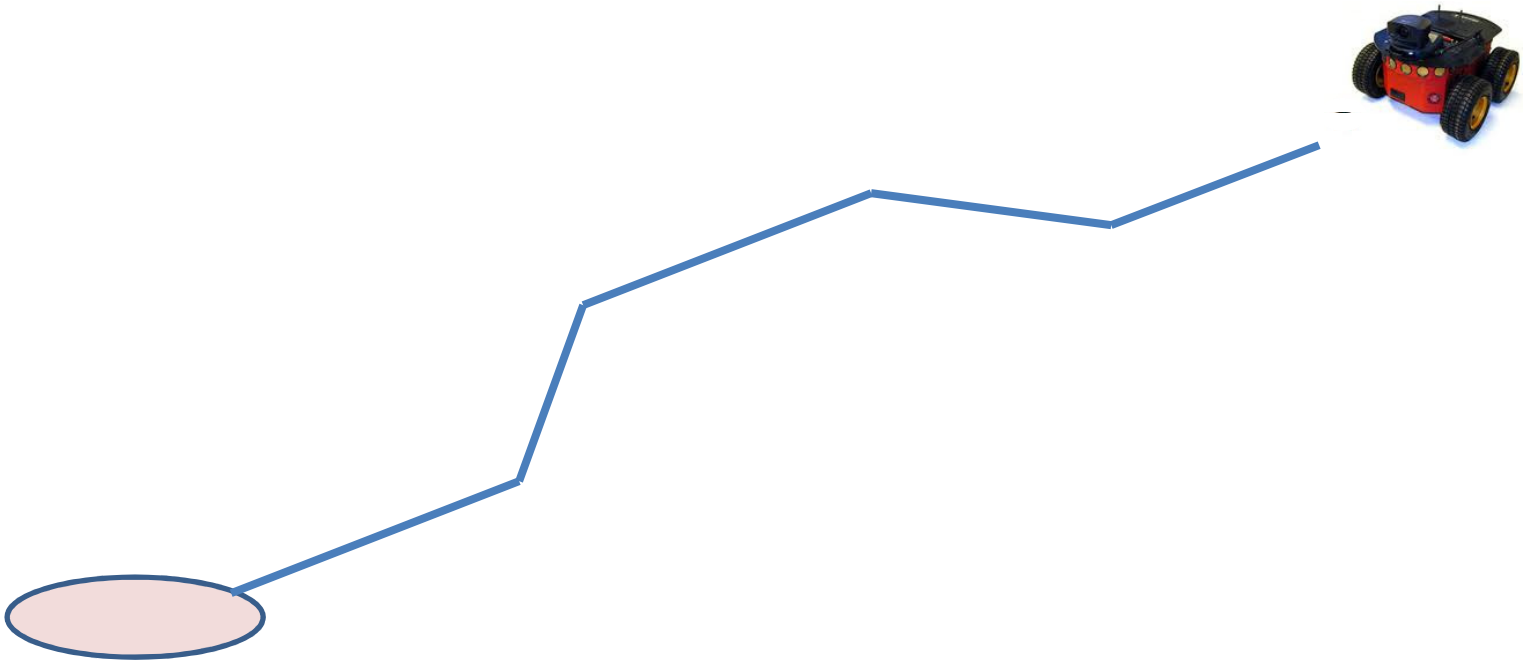


Topics

- SCU robotics program
- Multi-robot control systems
- Adaptive sampling

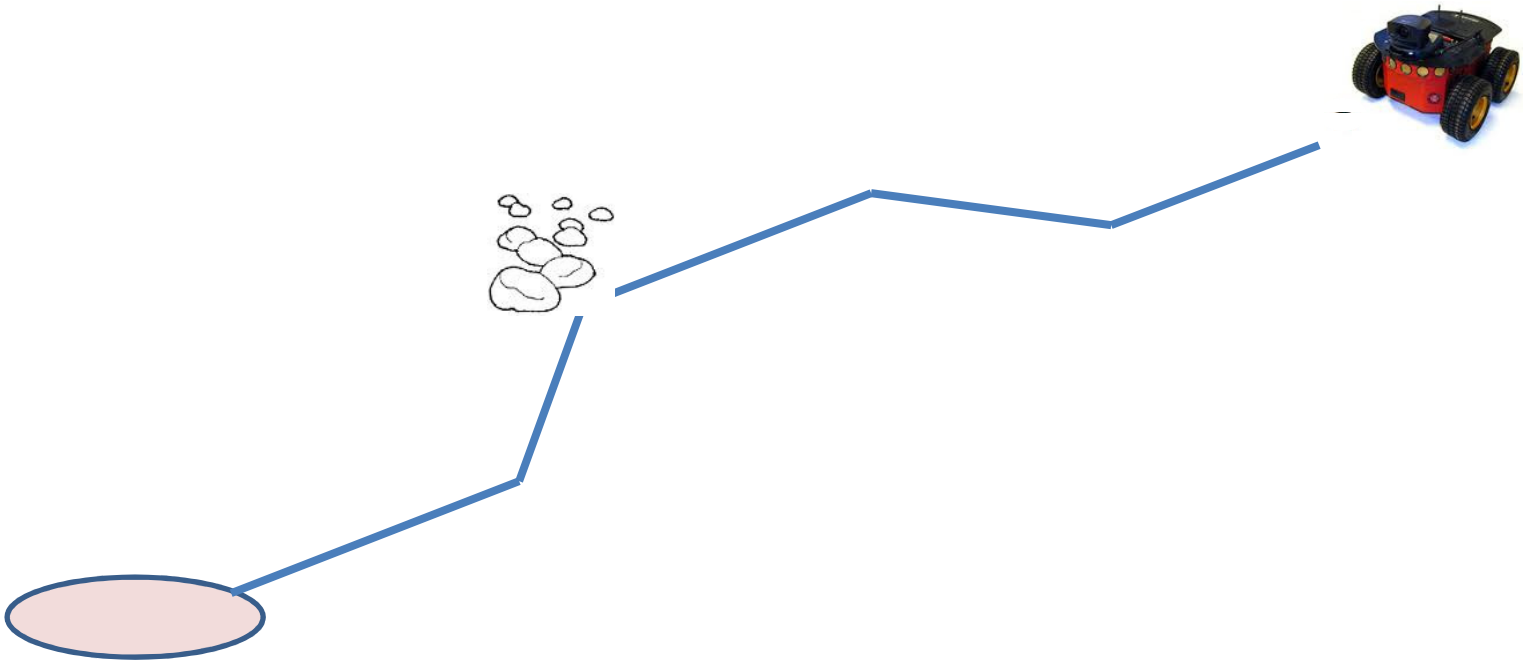
Navigation Approaches

- Standard navigation – follow a pre-planned path



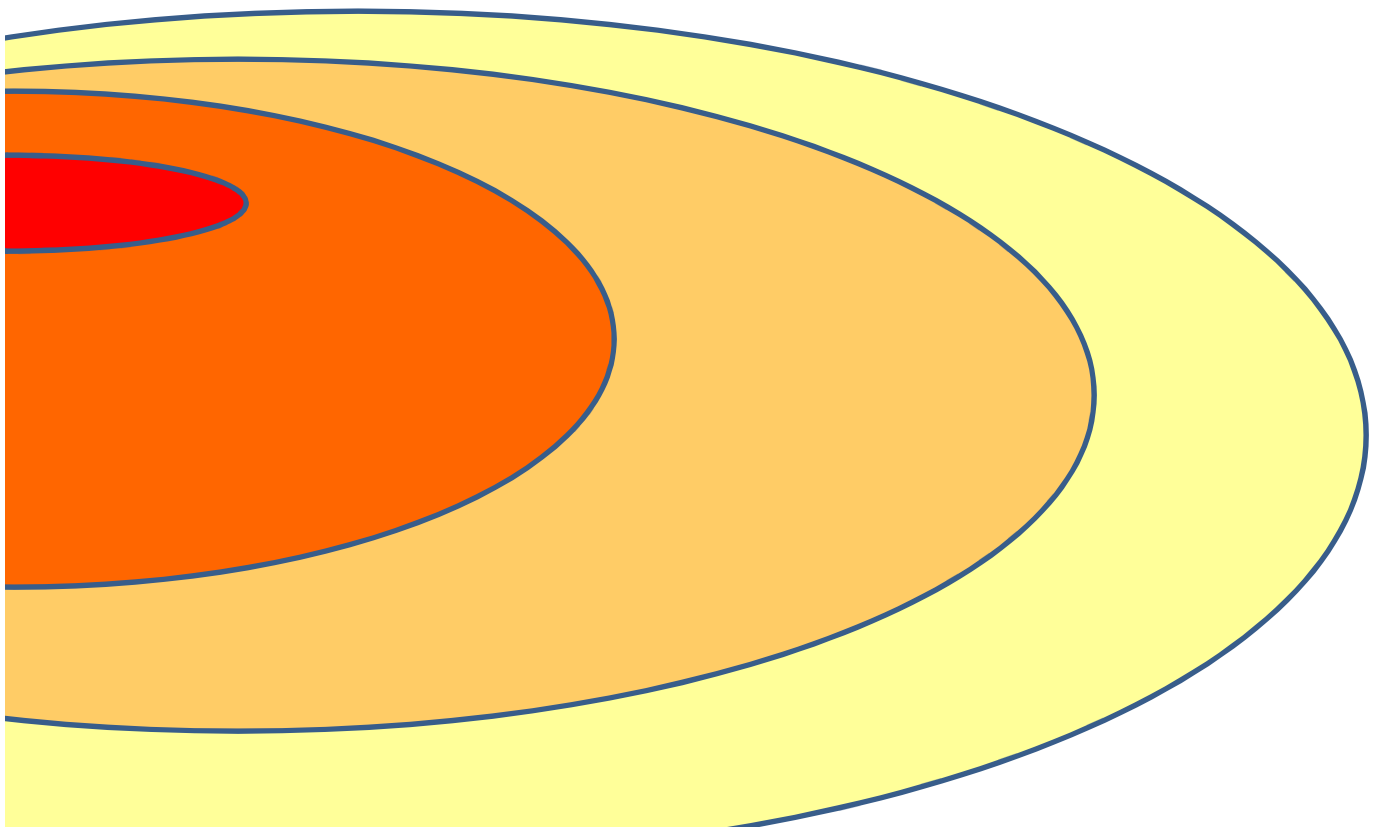
Navigation Approaches

- Adaptive navigation – update your path as you go



Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements



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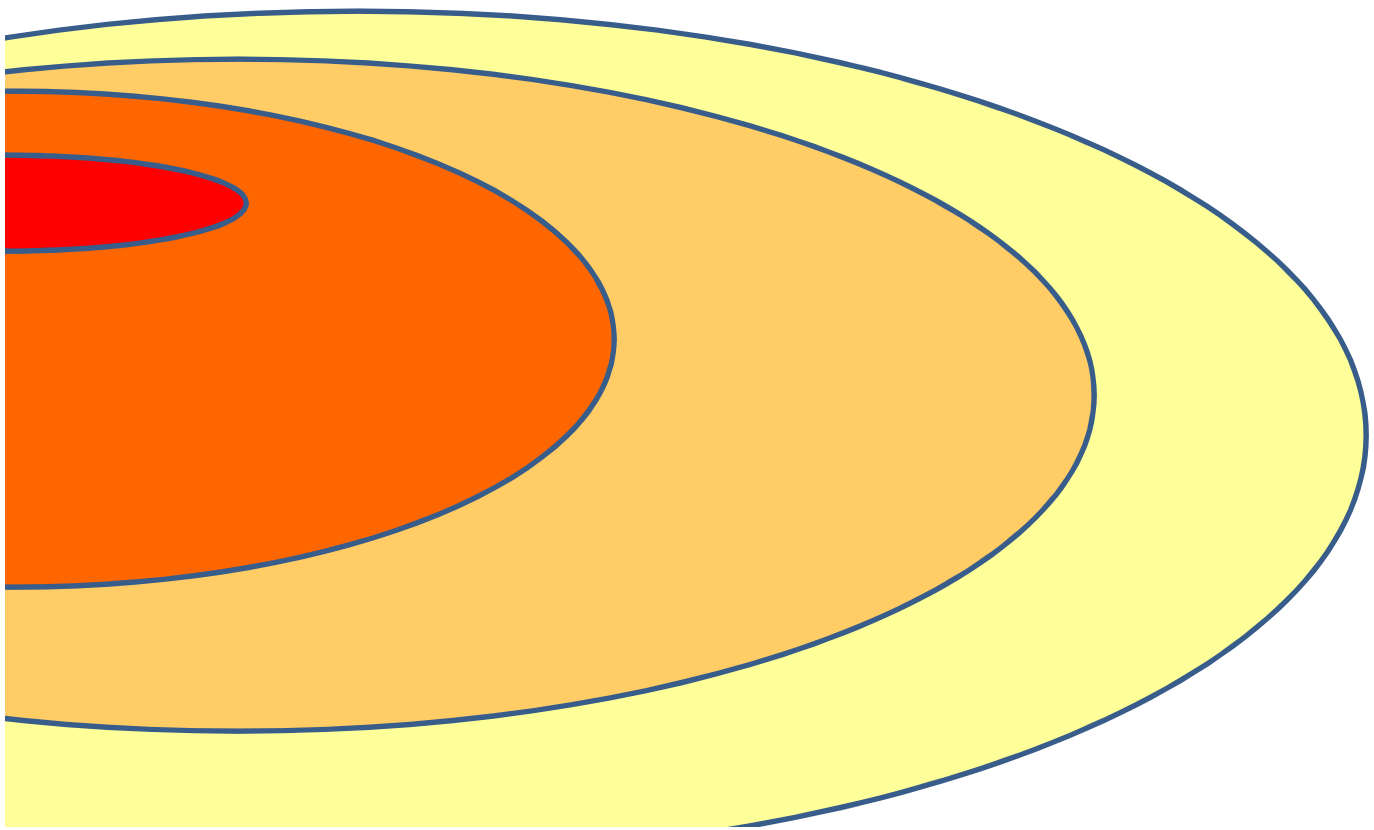
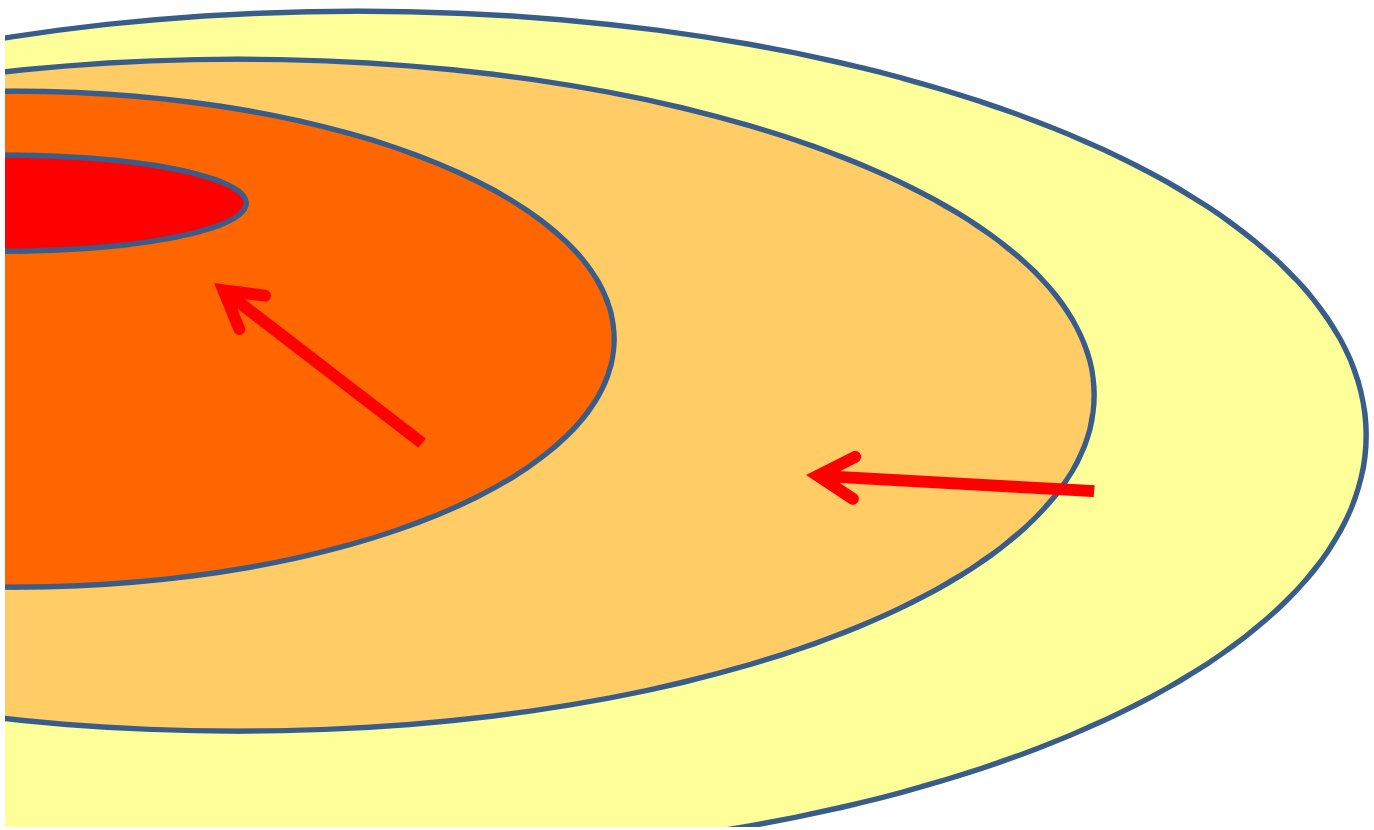


Find the hot spot. Read temperature, and change path.

Navigation Approaches

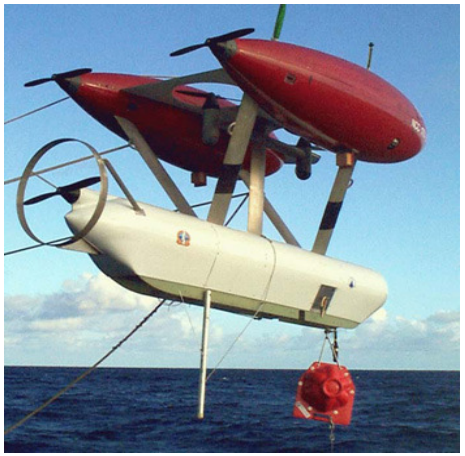
- Adaptive sampling – update your path AND your destination as you move by taking measurements



But – need to know what direction to travel – direction of maximum increase – the "gradient."

Adaptive Sampling

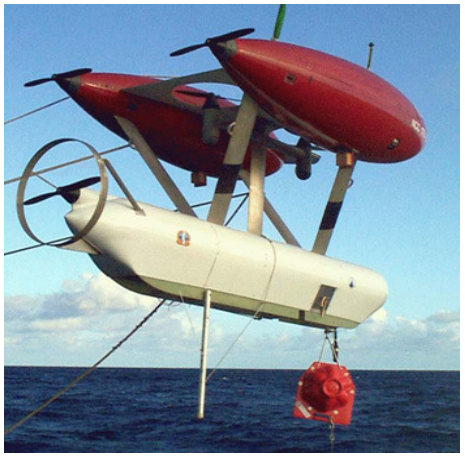
- A powerful concept
- Limited implementation in field
- Requires inefficient motion



Autonomous Benthic Explorer (Courtesy NOAA)

Adaptive Sampling

- A powerful concept
- Limited implementation in field
- Requires inefficient motion

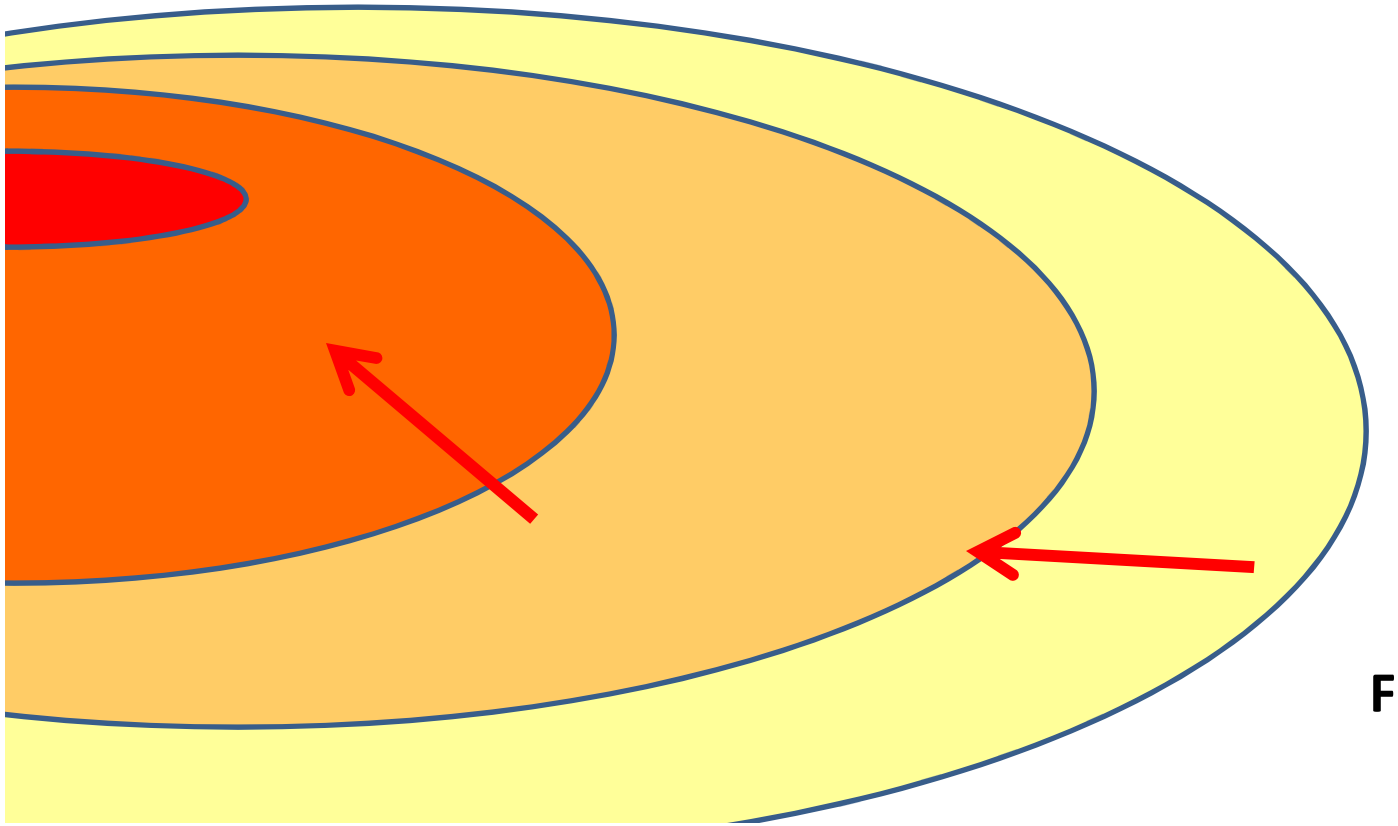


Autonomous Benthic Explorer (Courtesy NOAA)

- A group of robots can instantly sense gradient
  - Control formation to get good 2-D spread of samples
  - Wave of research in multi-robot adaptive sampling
  - BUT FEW HAVE DONE IT!!!

Navigation Approaches

- Adaptive sampling – update your path AND your destination as you move by taking measurements



Find the hot spot.

Navigation Approaches

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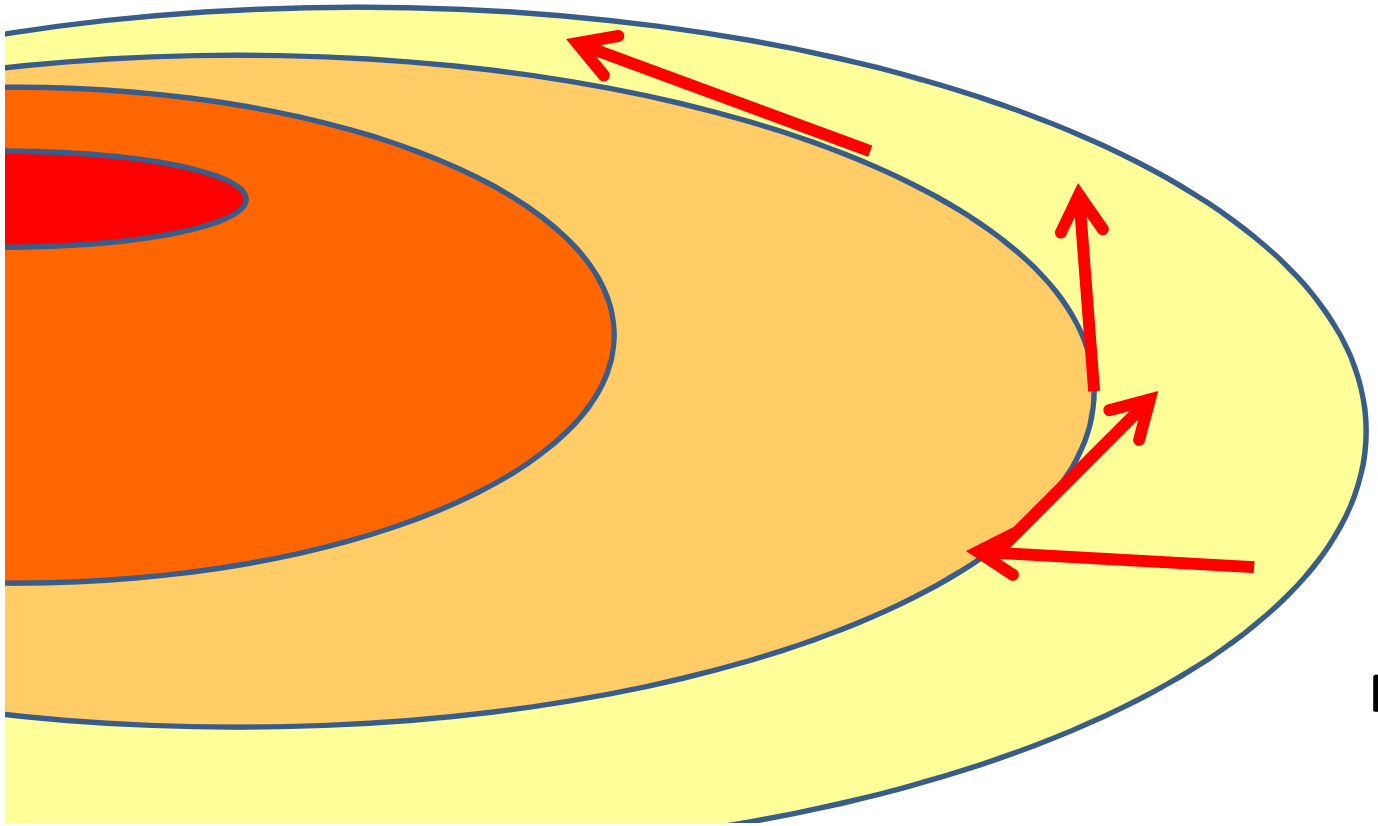
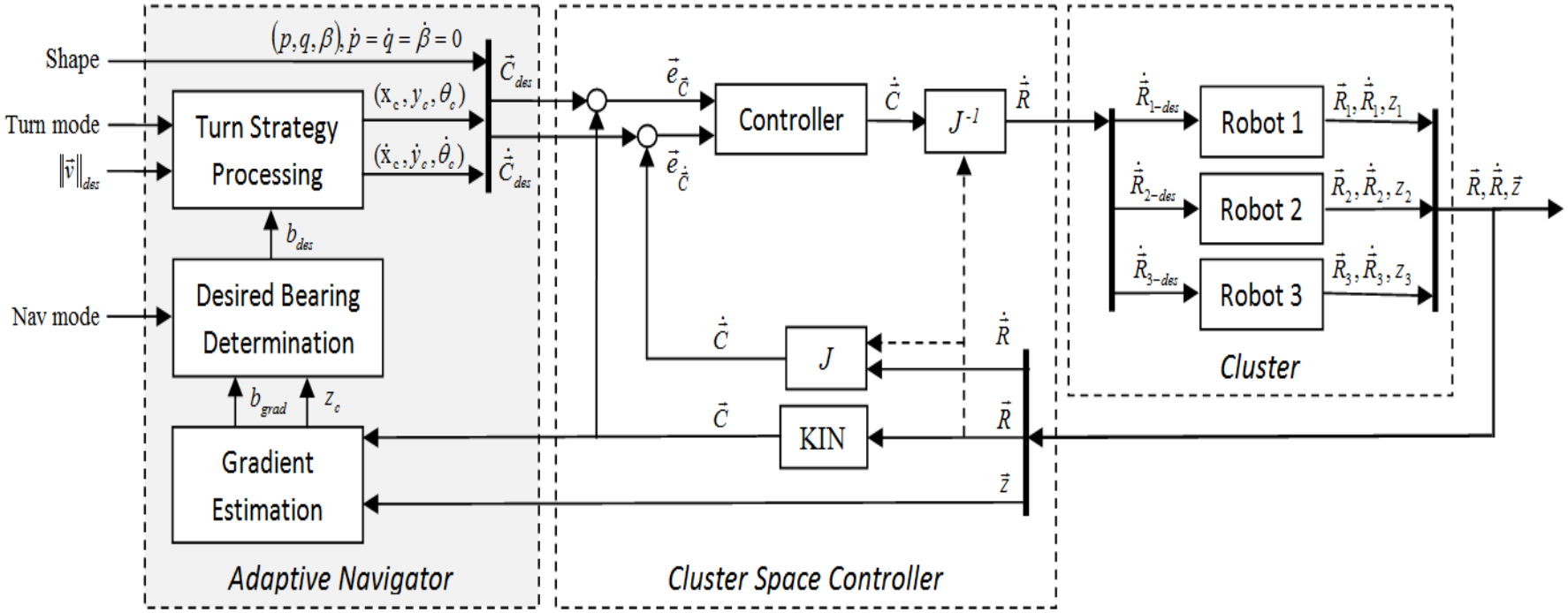


Patrol the perimeter

Adaptive Navigation Achieved

3 kayaks follow a contour & descend a gradient



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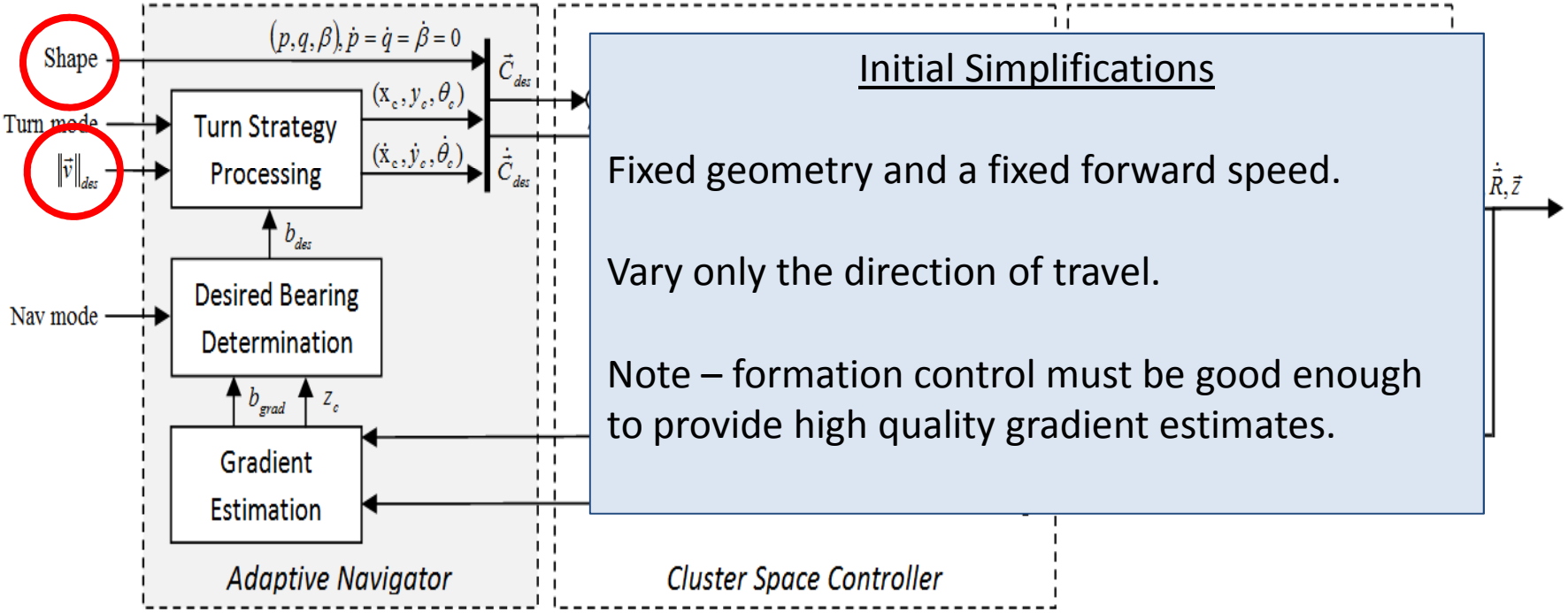

Adaptive Navigation Achieved

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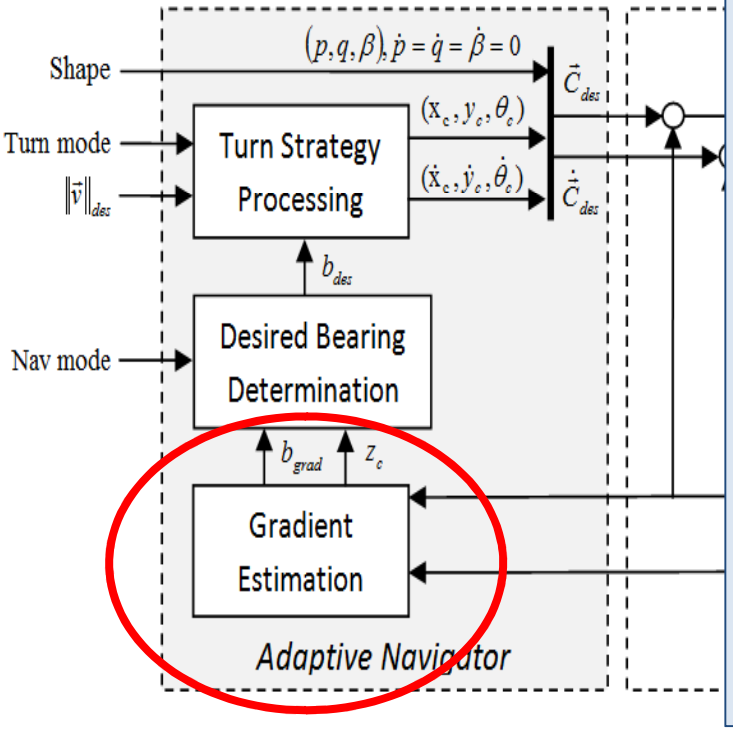
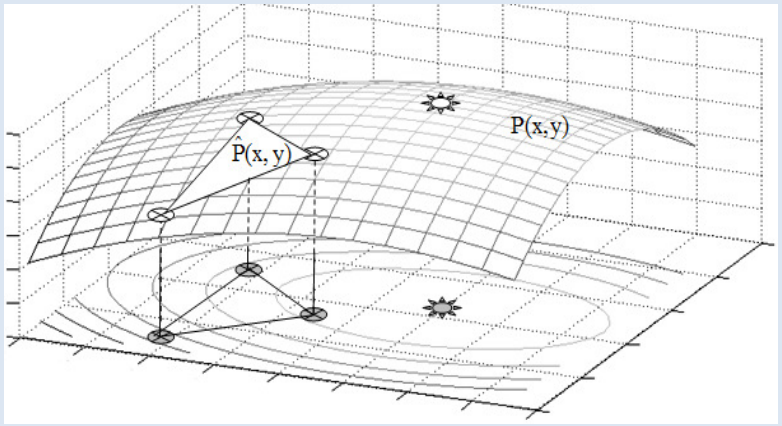


Gradient Estimation

Compute gradient given the instantaneous samples of the field from each distributed robot.



Adaptive Navigation Achieved

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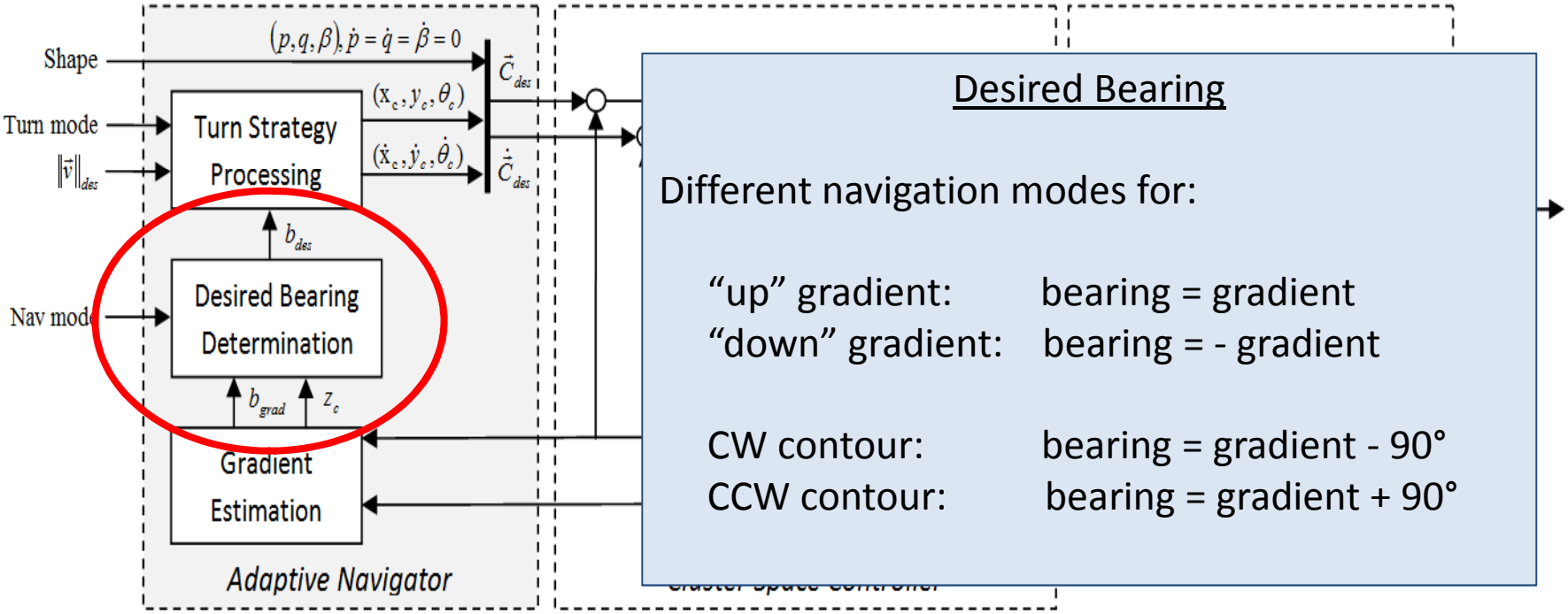

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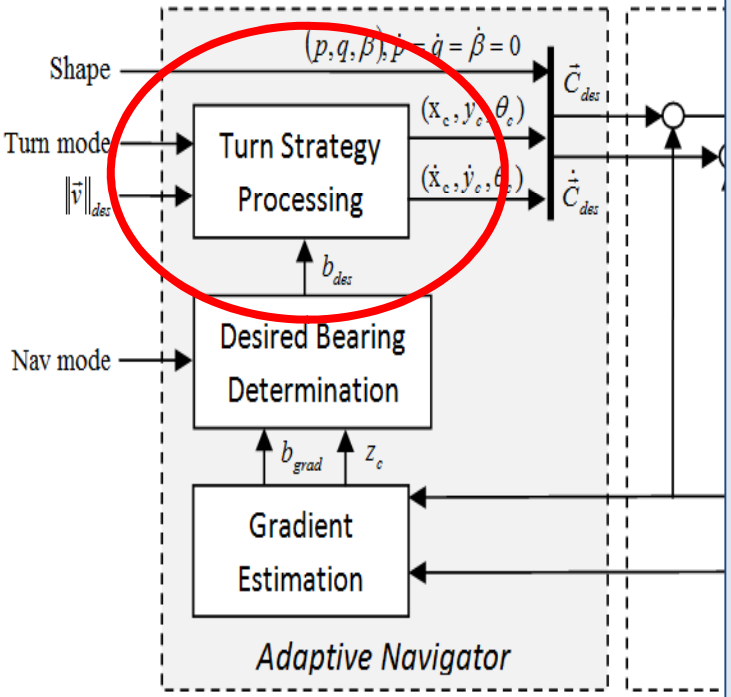
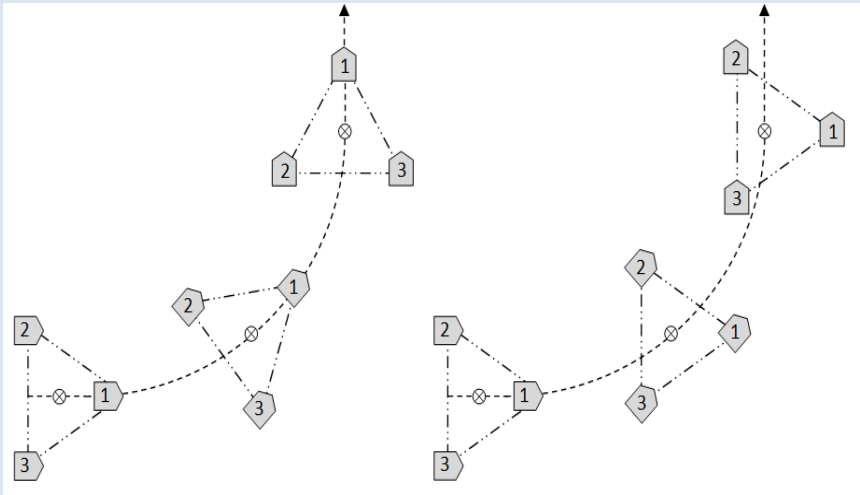


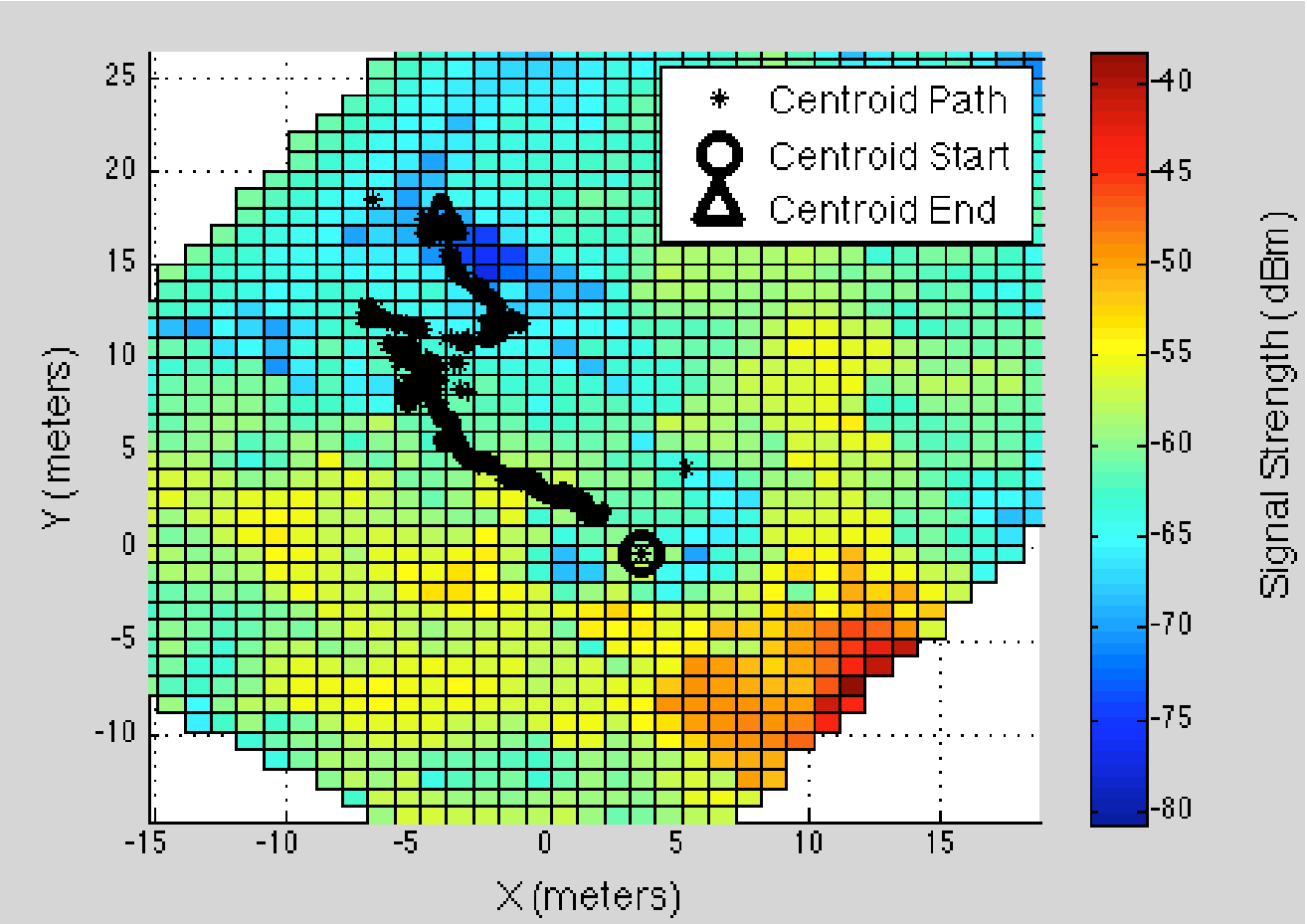
<u>Turn Direction</u>

Option for either an aggregate “column left/right” maneuver or a “flank” maneuver.



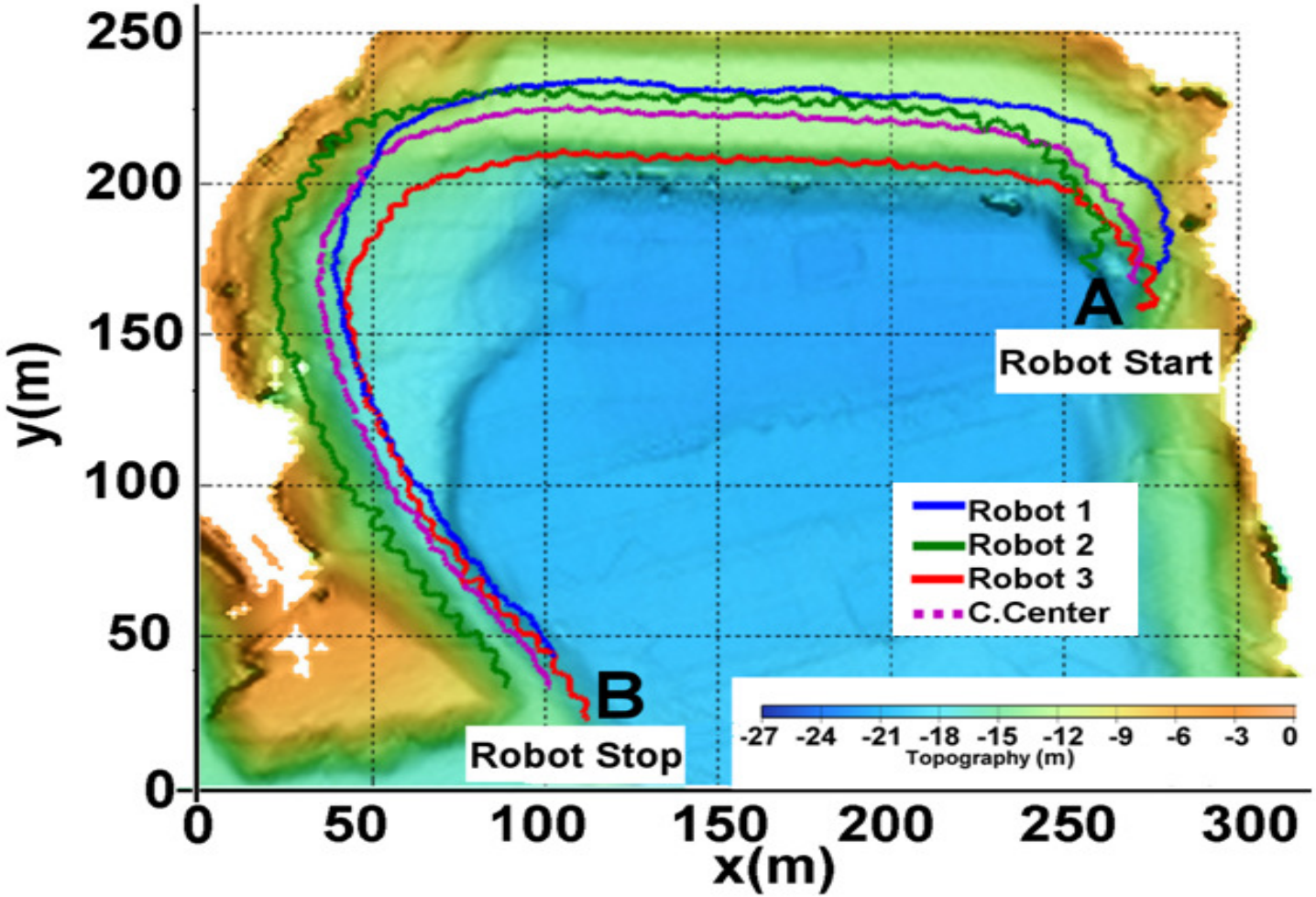
Adaptive Navigation Achieved

3 wheeled robots descend an RF field gradient



Adaptive Navigation Achieved

3 kayaks follow a bathymetric contour



Adaptive Navigation Achieved

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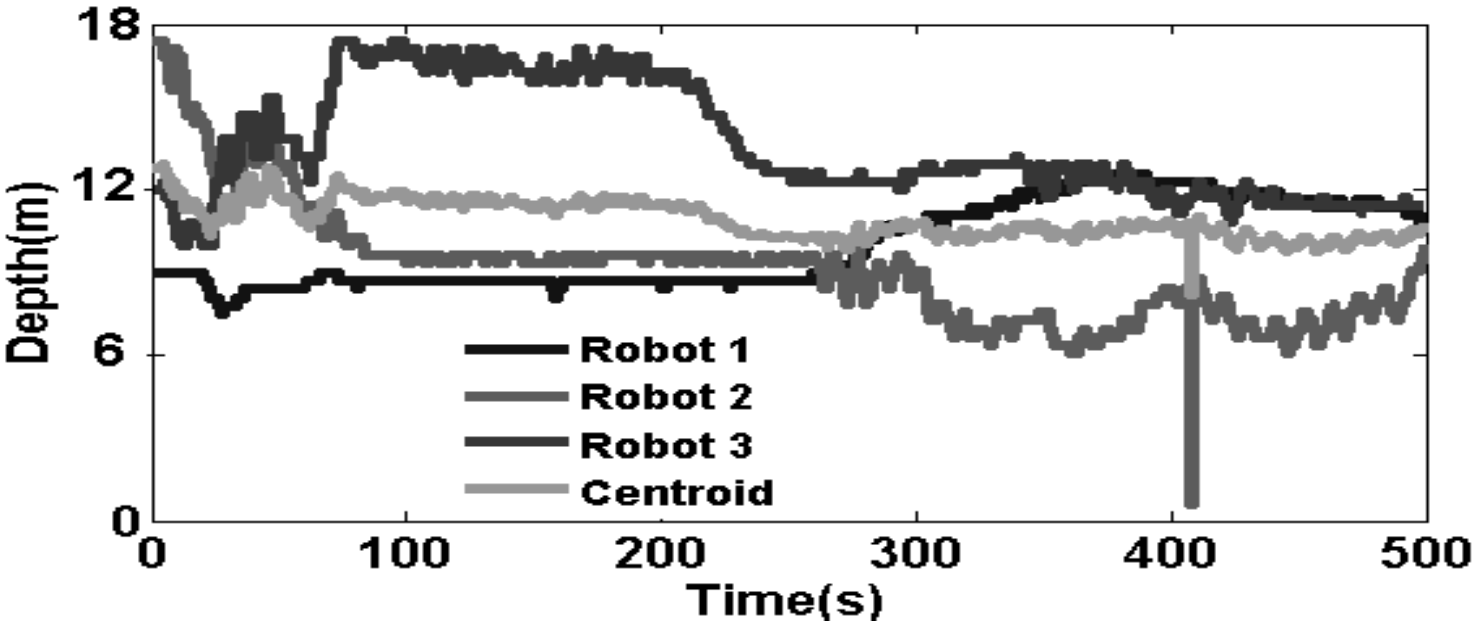
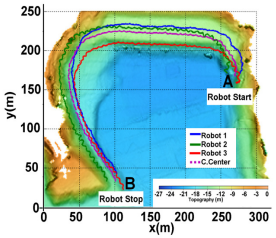


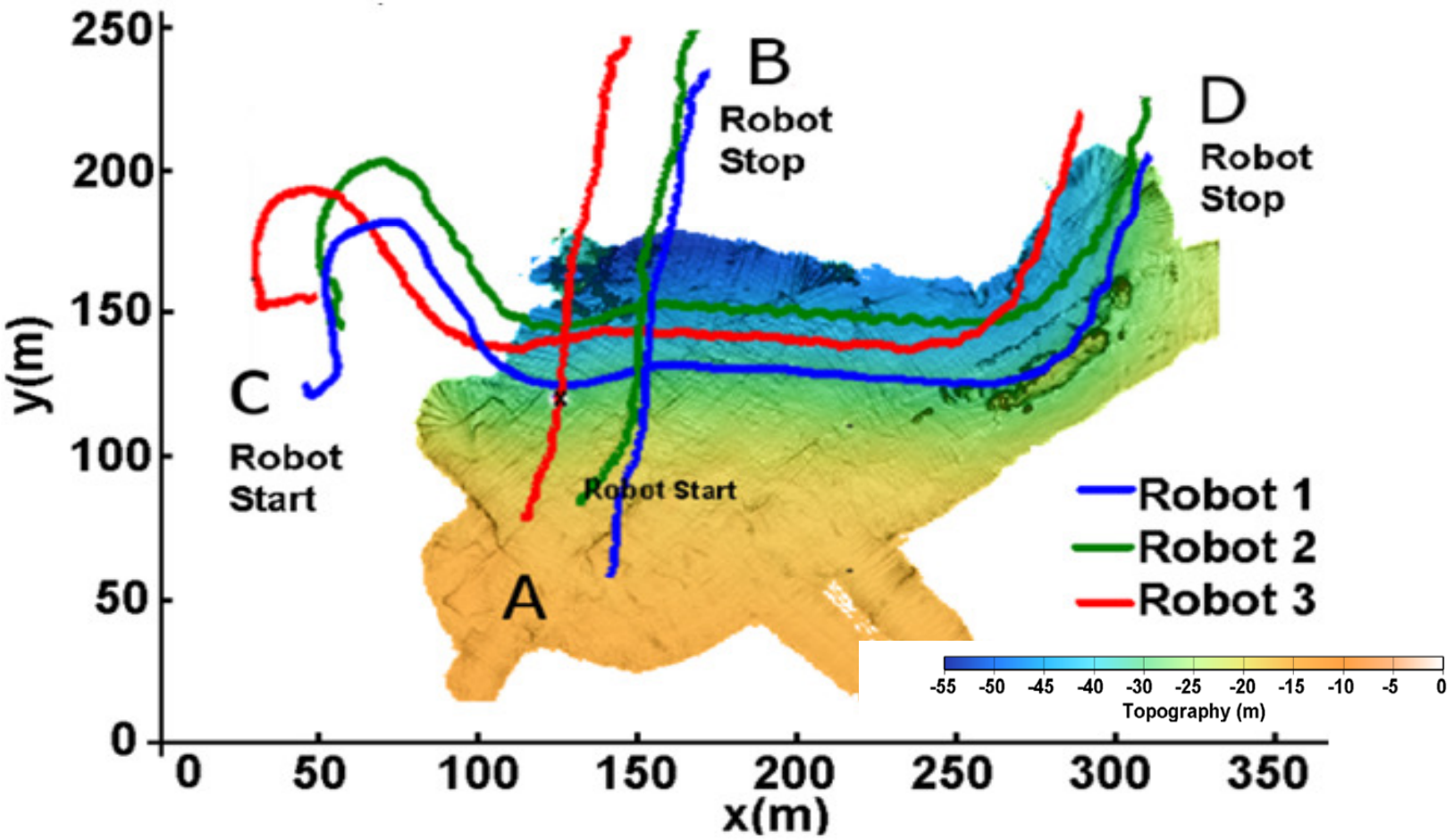


Contour Command: 11.5 meters
RMS Error: 1.2 meters
Sonar Accuracy 1 meter

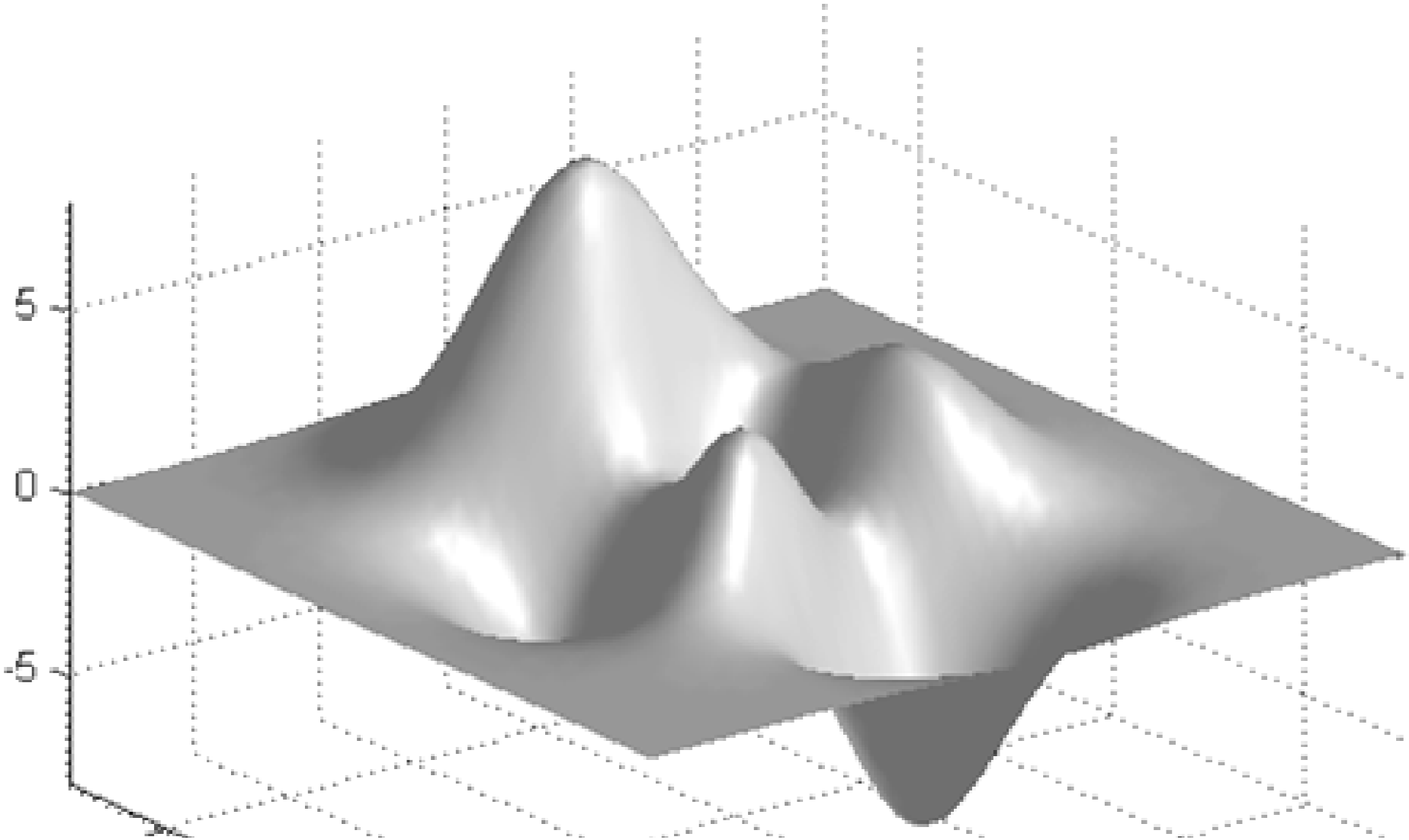
Truth Data
Produced by SCU
SWATH Boat

Adaptive Navigation Achieved

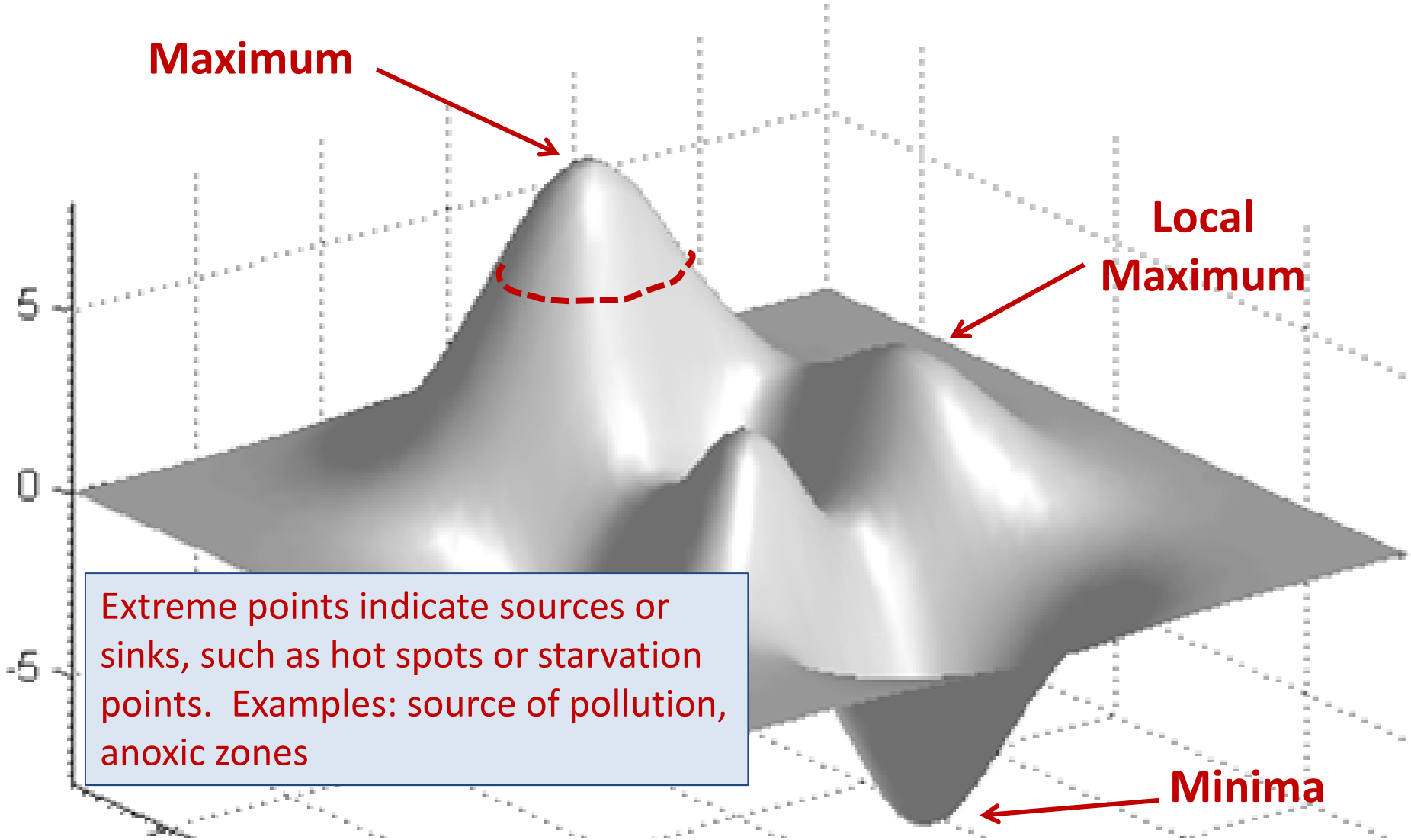
3 kayaks follow a contour & descend a gradient



General “Scalar” Field

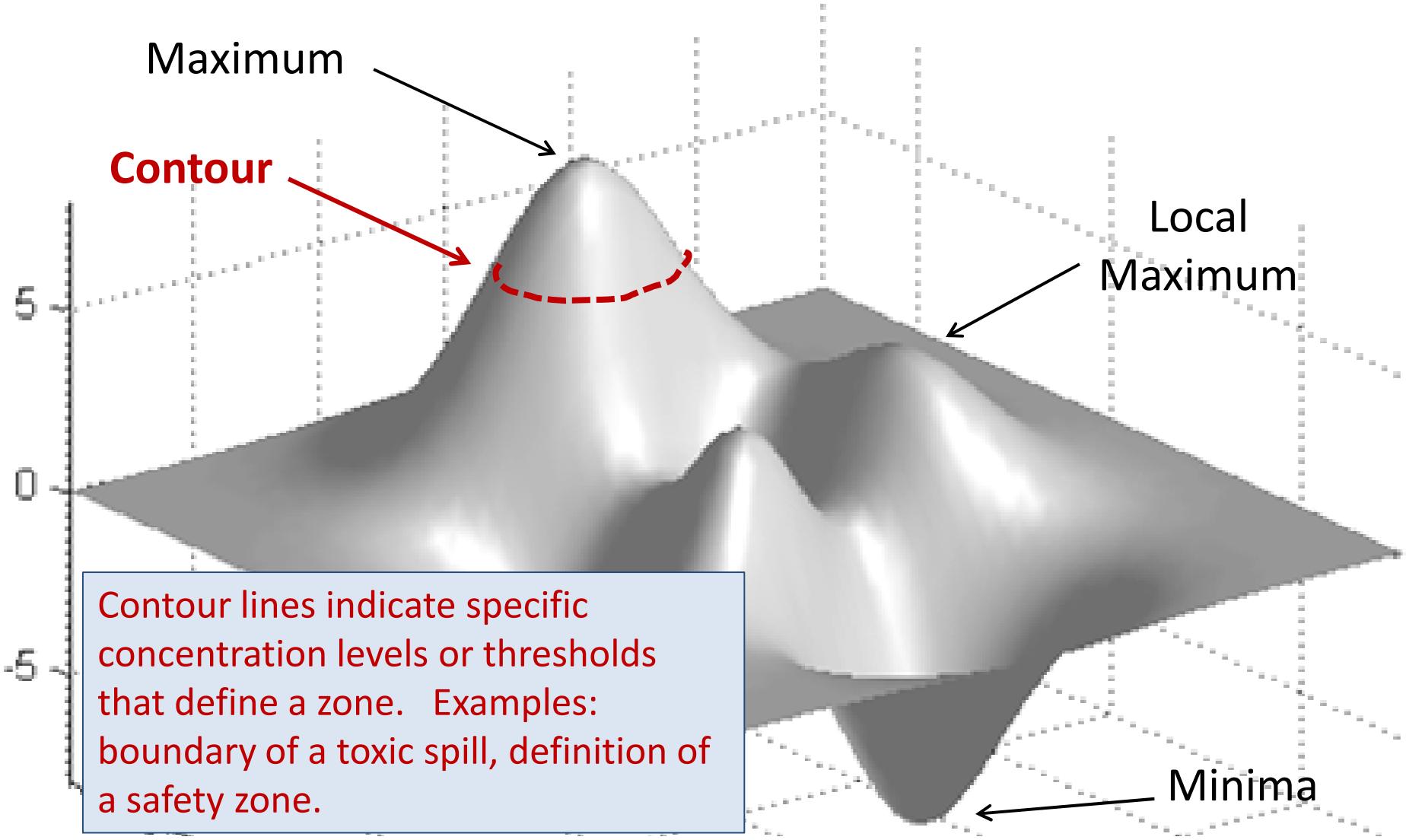


General “Scalar” Field



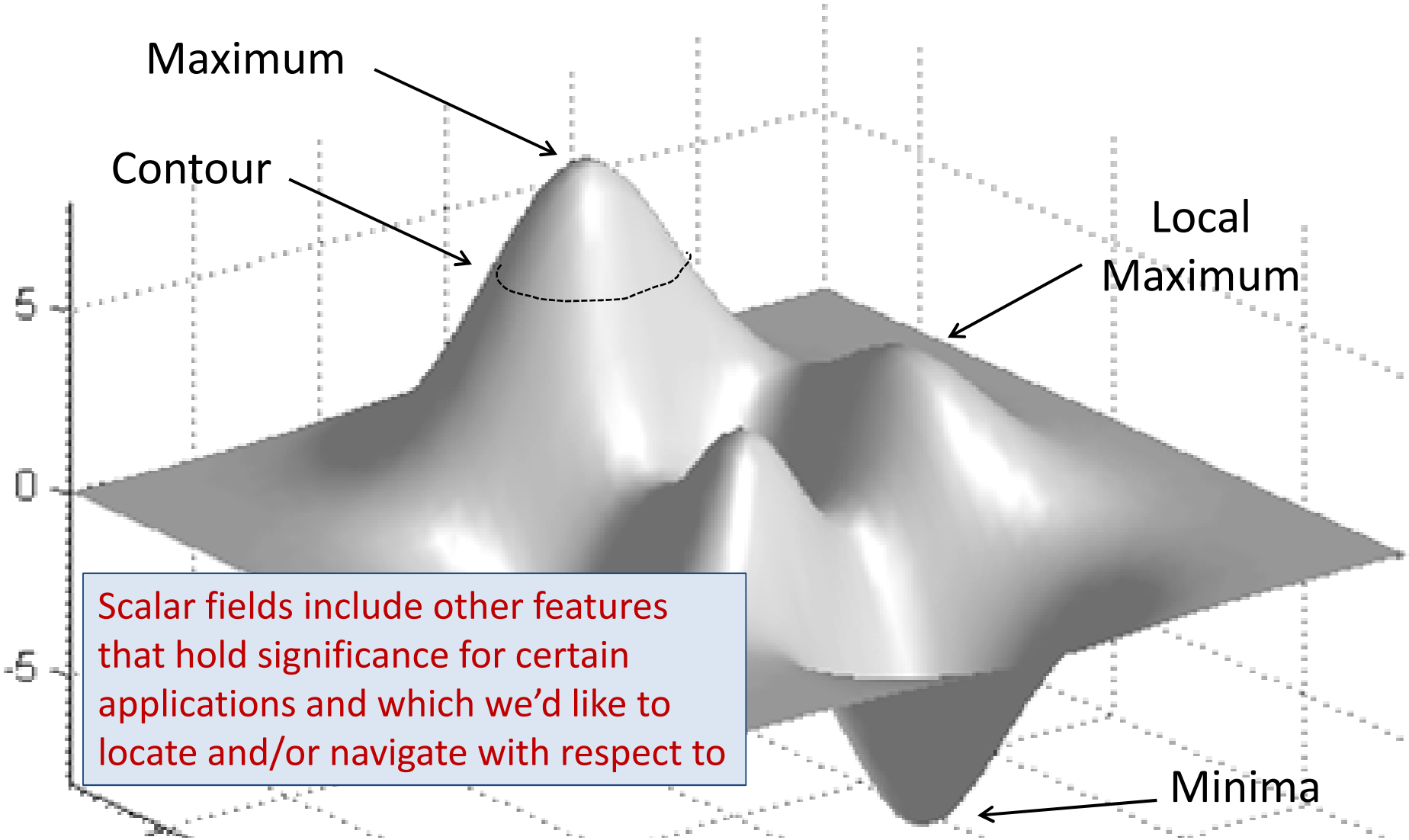
Extreme points indicate sources or sinks, such as hot spots or starvation points. Examples: source of pollution, anoxic zones

General “Scalar” Field



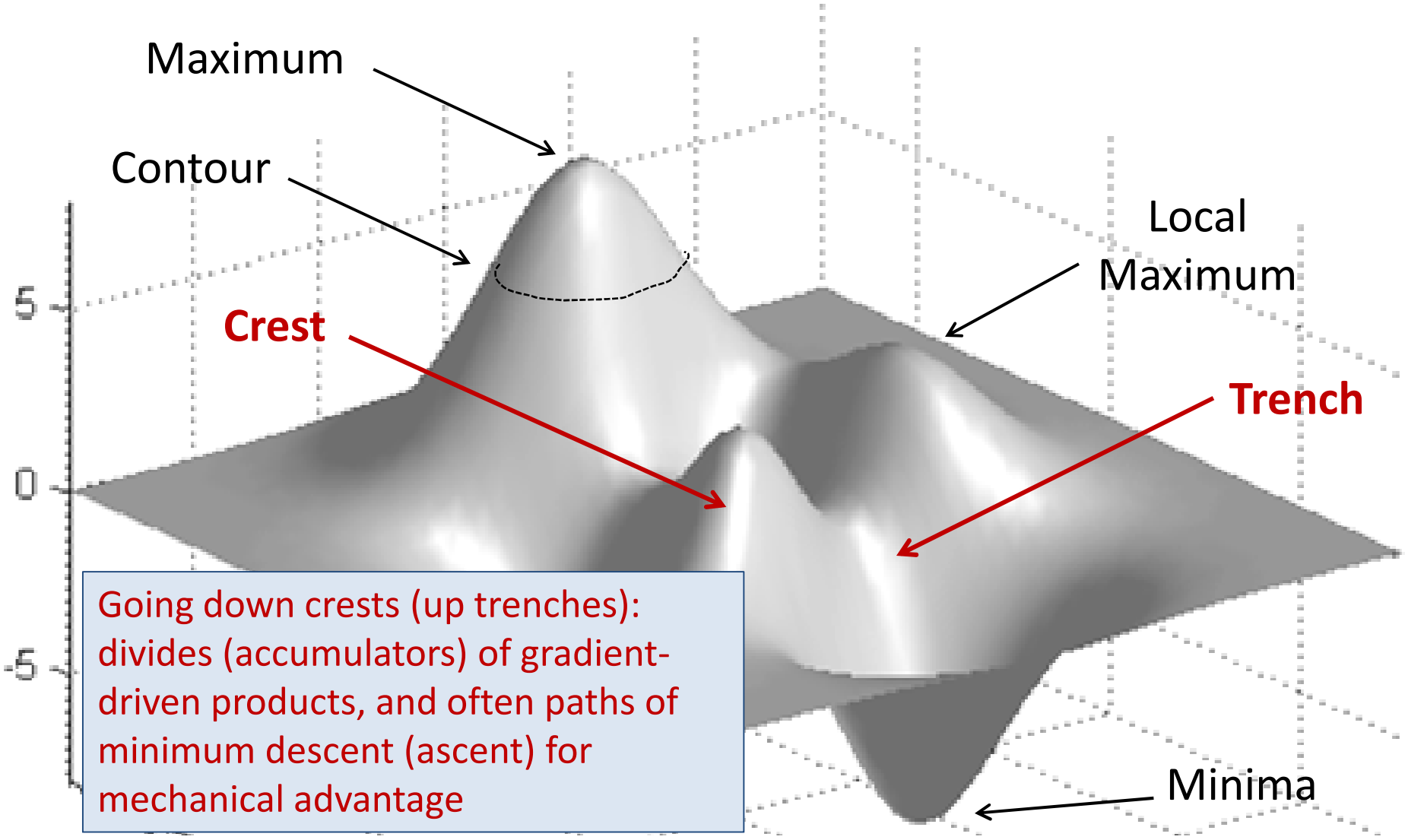
Contour lines indicate specific concentration levels or thresholds that define a zone. Examples: boundary of a toxic spill, definition of a safety zone.

General “Scalar” Field



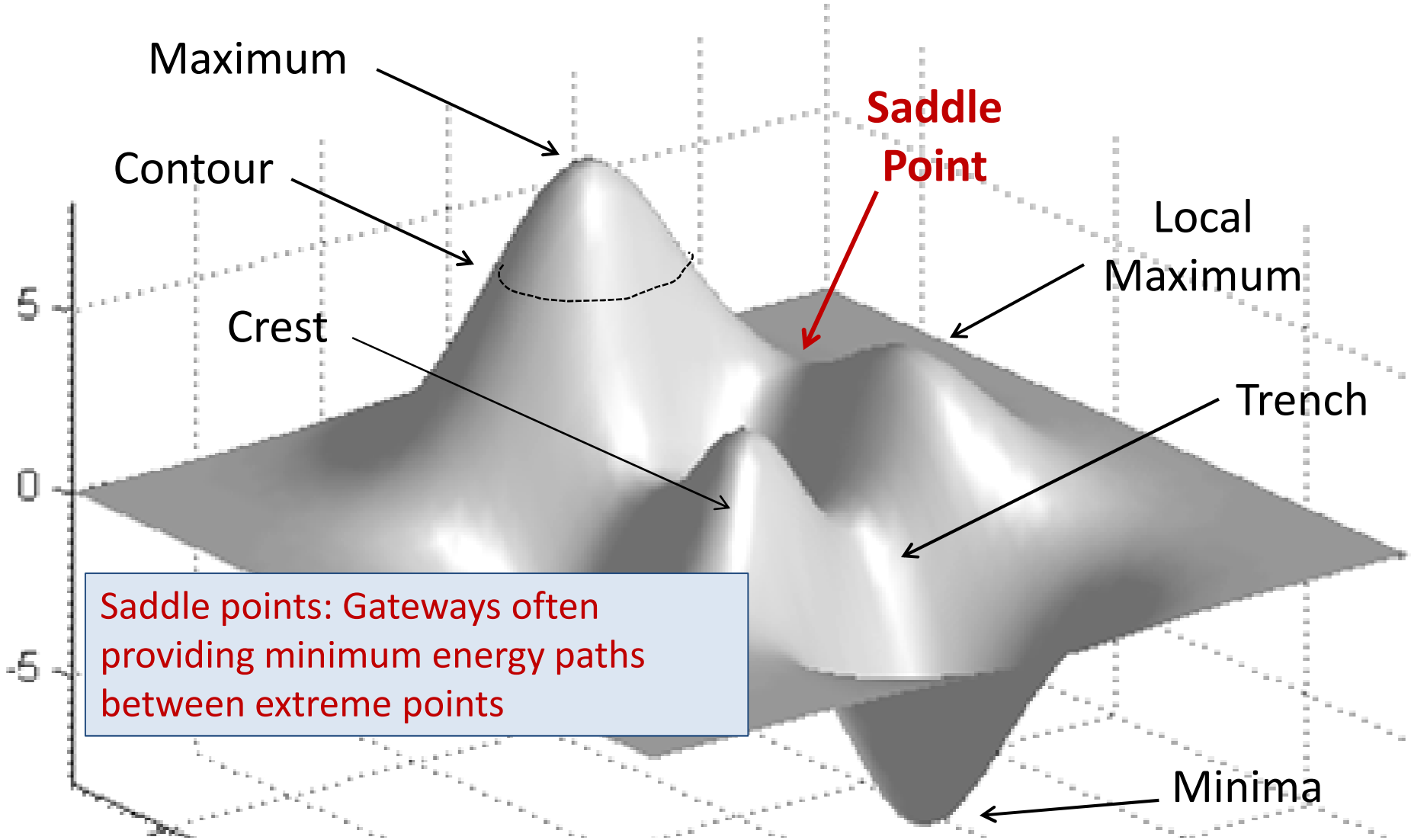
Scalar fields include other features that hold significance for certain applications and which we’d like to locate and/or navigate with respect to

General “Scalar” Field



Going down crests (up trenches): divides (accumulators) of gradient-driven products, and often paths of minimum descent (ascent) for mechanical advantage

General “Scalar” Field



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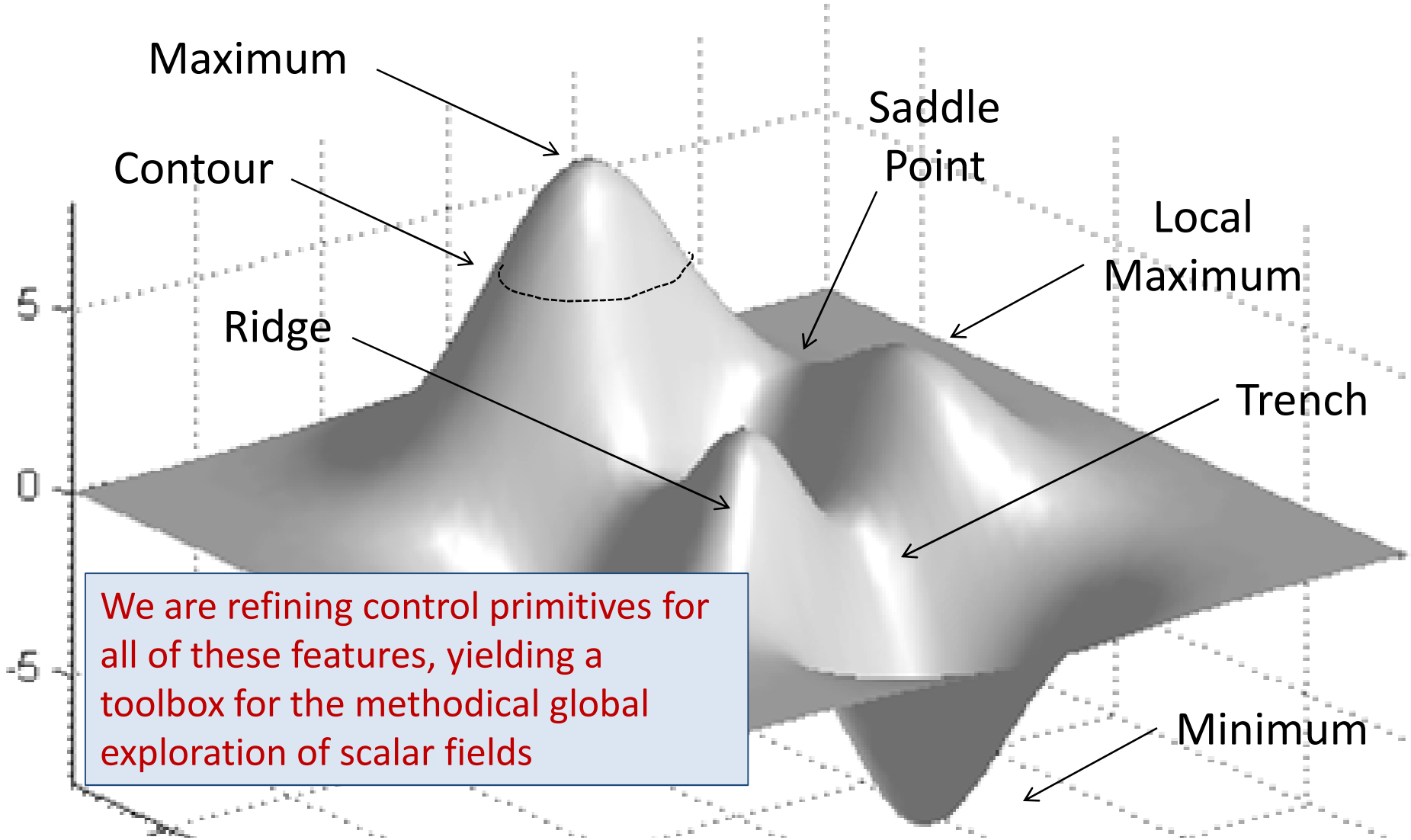

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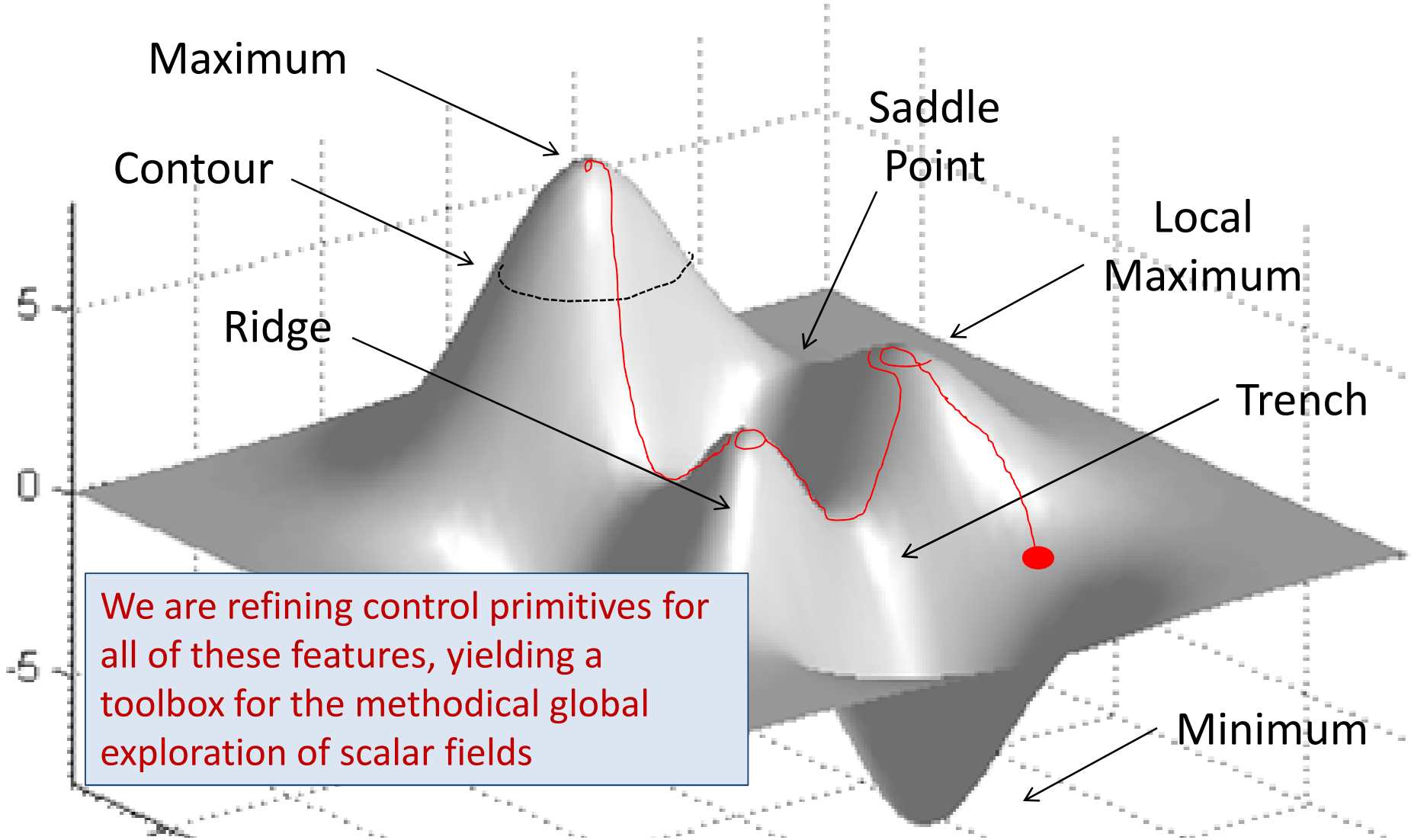

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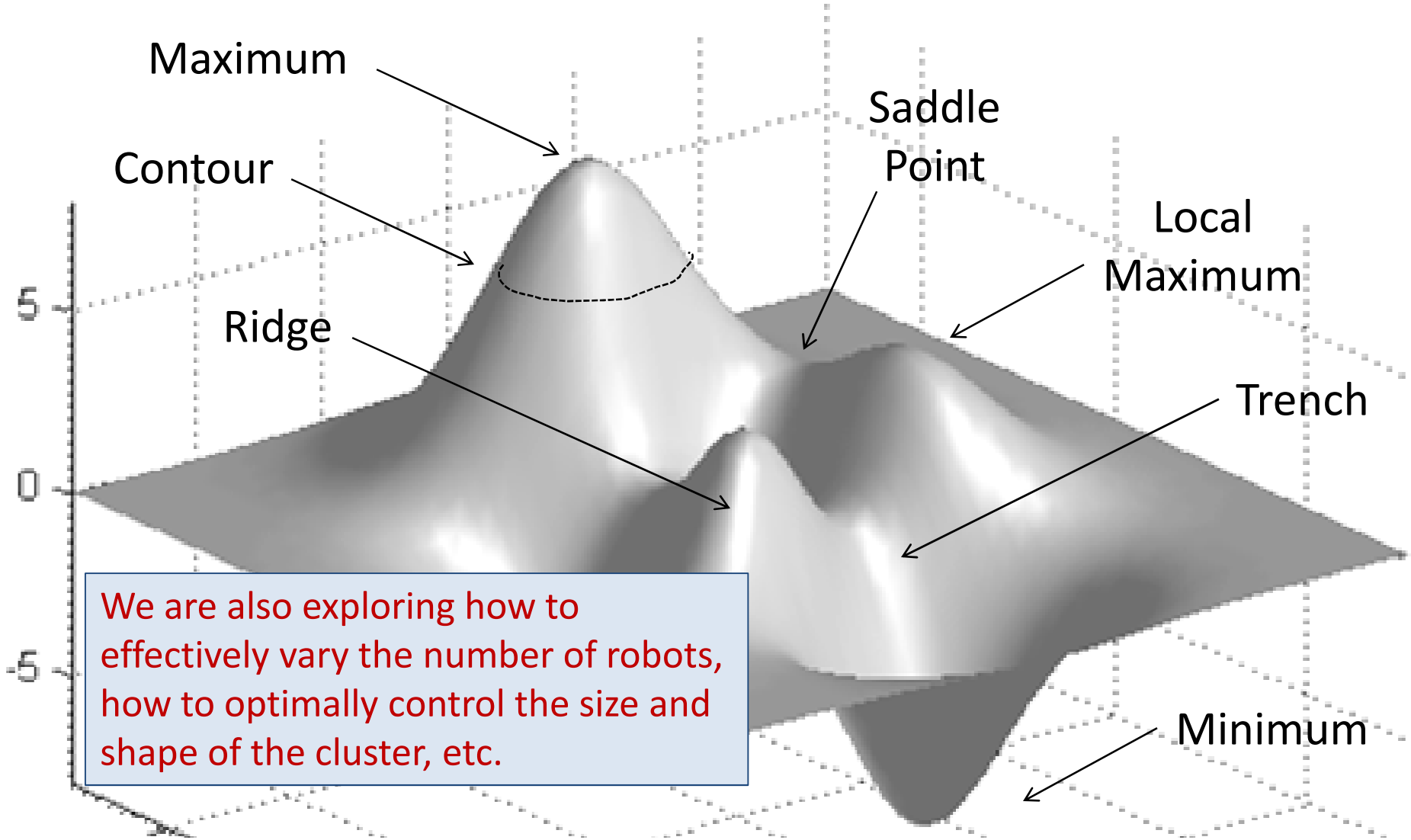
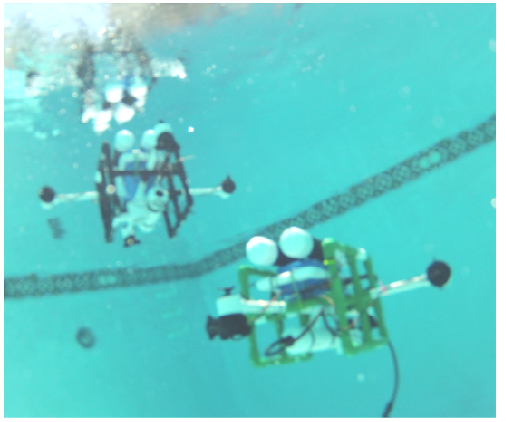


We are also exploring how to effectively vary the number of robots, how to optimally control the size and shape of the cluster, etc.

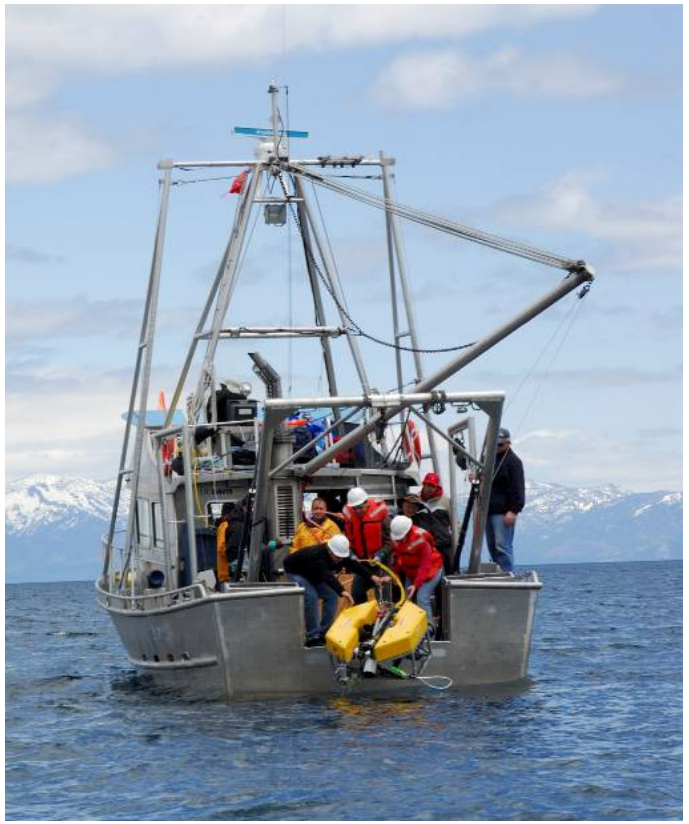
Ongoing & Future Work

- Comprehensive Adaptive Sampling
  - All primitive capabilities
  - Consolidated motion strategies
- 3-dimensional fields & vector fields
  - Aerial vehicles, ROV/AUVs, spacecraft
- Different types of fields
  - Terrain, RF, Chemical
  - Thermal, Turbidity
- Real field missions?
  - Oil spills
  - Pollution plumes
  - Hydrothermal vents



Summary

- Exciting & comprehensive field robotics program
- Particular interest in fielding multi-robot tasks with underlying formation control capabilities
- Initiative in multi-robot adaptive navigation for exploring scalar fields



Questions?

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