Sensor Networks

Evolution, Opportunities, and Challenges

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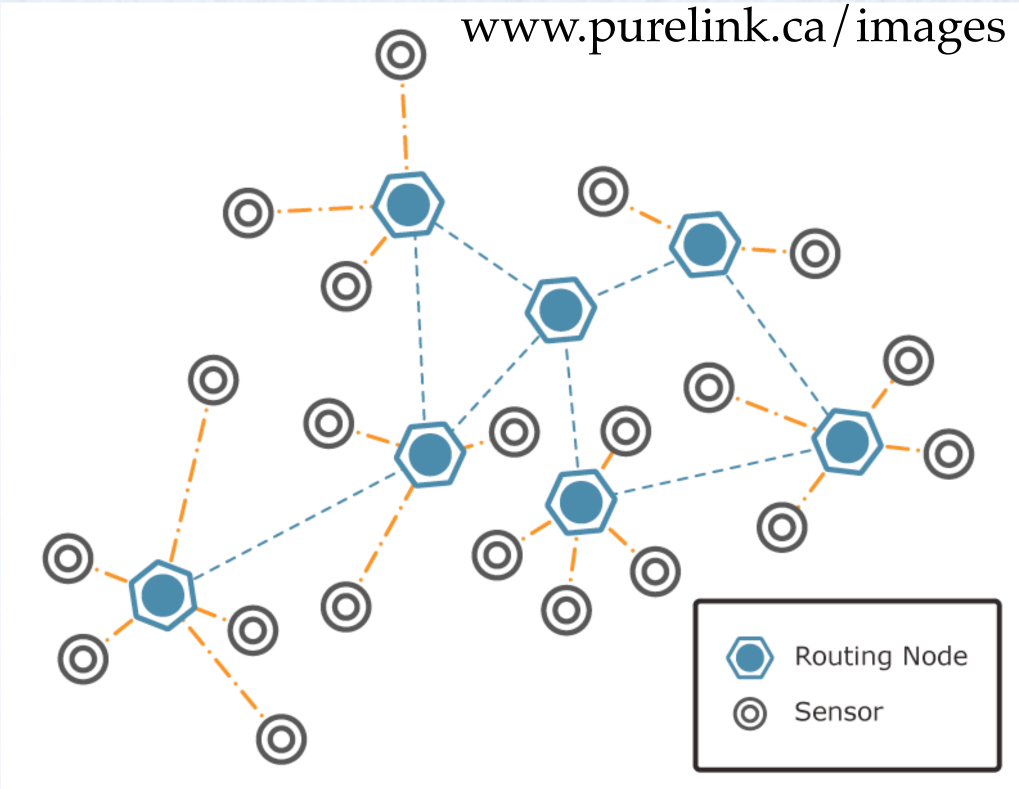
Outline

- Introduction
- History of Sensor Networks
  - Research Progress
- Applications of Sensor Networks
  - Trends of Technology
- Research Results
  - Hard Problems
- Applications
  - Environmental Observation

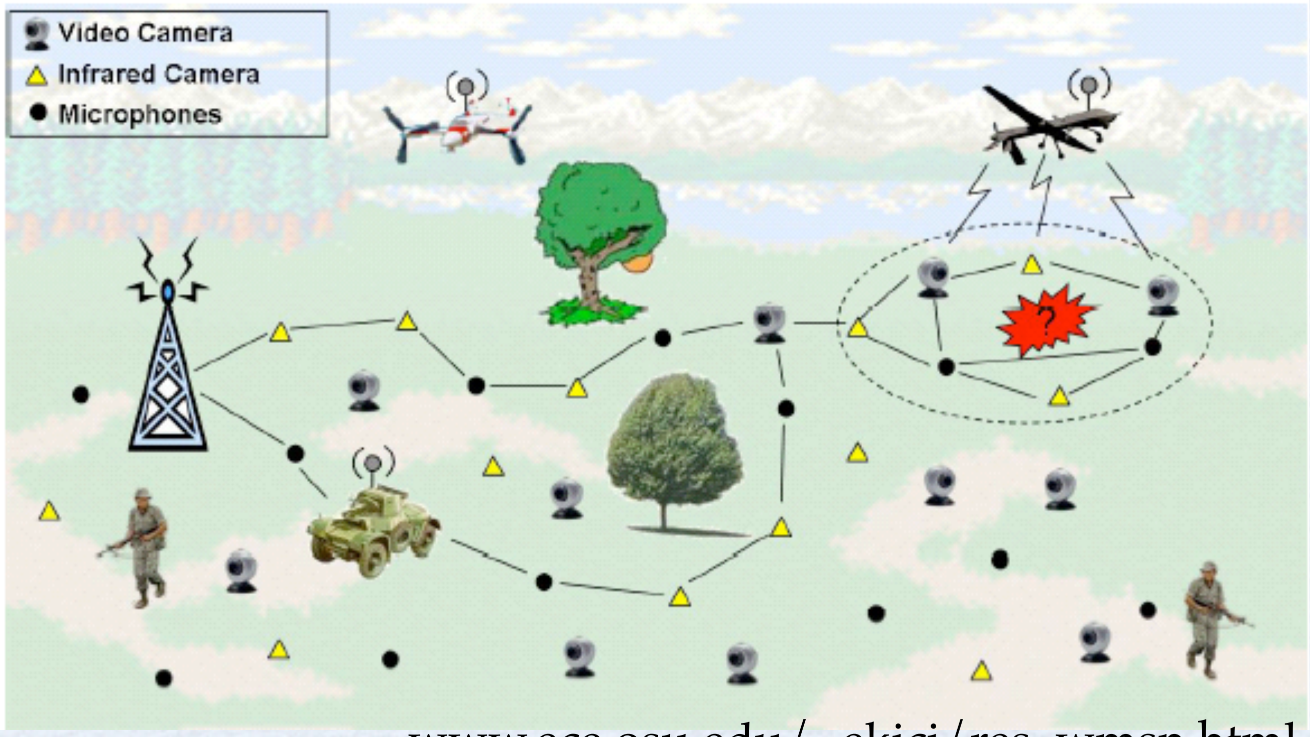
Distributed Networks

- Large Number of Smart Devices
  - Cheap, multiple sensors, small processing unit
- Sensor Capabilities
  - Acoustic, infrared, microradars, etc. pp.
- Communication
  - Wireless or wired links
- Site of Operation
  - Ground, under water, or on vehicles



Distributed Networks

- Different Applications
  - Military, environment
  - Air traffic, surveillance
  - Manufacturing
- Big Differences
  - Share common technical issues



www.ece.osu.edu/~ekici/res_wmsn.html

Characteristics

- Point of Signal Processing
  - Observation, sampling, and communication
  - Discrete Approximation
- Reproduce Distributed Signal
  - Key characteristics
  - Limited Resources
- Two Approaches
  - Centralized vs. Distributed

Centralized Approach

- Data Acquisition
  - Sensors just gather data
  - Raw data to central processing unit
- Centralized Unit
  - Processed jointly and simultaneously
- Drawback
  - Vast amount of data
  - Energy and bandwidth constrains

Distributed Approach

- Problem of Scaleability
- Introduce Signal Processing
  - Process data at sensor directly
  - Reduce size - extract useful information
- Balance the Reasons
  - Sensing - Processing - Transmission
- Distributed Computing
  - Process the data

History of Networks

- Research Areas
  - Sensing, communication, and computing
- Military Sensor Networks
- Defense Advanced Research Projects Agency
- Networks from 1980 to 2000
- Current Research Projects

Early Research

- Sound Surveillance During Cold War
  - Monitor Soviet submarines
  - These days: Ocean and animal activities
- Air Defense Radar
  - Airborne warning and control
- Hierarchical Networks
  - Ideally suited for military

Sensors at DARPA

- Defense Advanced Research Projects Agency
- *ARPAnet* (predecessor of the Internet)
  - Extend existing knowledge
- Low Cost Nodes that Communicate
- Minicomputers
  - *PDP11* and *VAX* with *Unix* or *VMS*
- First Approaches
  - Acoustic sensors, resource sharing networks, Distributed networks

Early Research

- Communication Oriented OSs
  - Accent (*Mach*) by CMU, Pittsburgh
- Load Balancing
  - Interprocess communication
- Knowledge Based Systems
  - Human heuristics for interpretation
  - Tracking helicopters

Helicopter Tracking

Acoustic Array

Equipment Rack

Mobile Node

A Sensor's History - The 80s

- Evolution over One Decade
  - Military systems
  - Weapons equipped with sensors
- Fixed Distributed Systems *FDS*
- Advanced Deployable System *ADS*
- Remote Battlefield Sensor Systems *REMBASS*

A Sensor's History - The 80s

- Microelectromechanical Systems
  - Small and inexpensive sensors
  - Wireless links for ad-hoc networks
  - Low power processors
- Research Progress
  - Computation and communication
- *DARPA*
  - Research program *SensIT*

DARPA's SensIT

- *DARPA* Sensor Information Technology
  - Ad-hoc deployment in dynamic environments
  - Network information processing
- Sensors are Interactive and Programmable
  - New affords
- Software
  - Lower latency, energy efficient operations, autonomy

Current Market

	Yesterday	*Today*	*Tomorrow*
Size	*Large Shoe Box*	*Pack of Cards*	*Dust Particle*
Weight	*Kilograms*	*Grams*	*Negligible*
Architecture	*Separated*	*Mixture*	*Integrated*
Power Supply	*Large Batteries*	*AA Batteries*	*Solar*

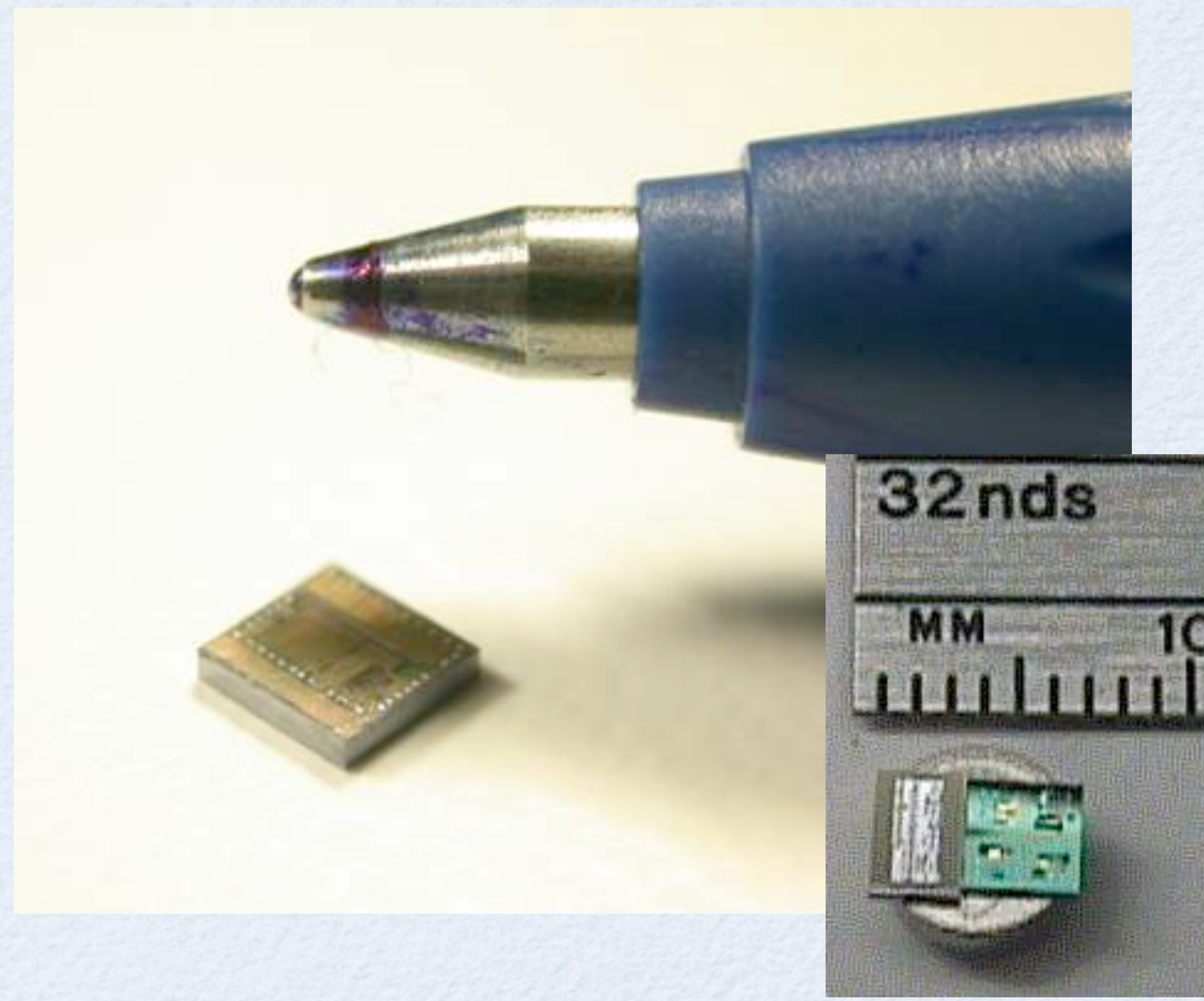
Applications

- Motivation by Military
  - Surveillance
- Every-day's Life
  - Lower costs, better technology
- Company Overview
  - Ember (`www.ember.com`)
  - Crossbow (`www.xbow.com`)

www.ember.com/pdf/brochure.pdf

Smart Dust

- Dust Inc., Berkeley, California
- Size and Design
  - Grain of sand
  - Sensor
  - Processor
  - Communication
- Utilisation
  - Currently military only



www.jlhlabs.com/jhill_cs/spec/index_files/image031.jpg

robotics.eecs.berkeley.edu/~pister/SmartDust/

Infrastructure Security

- Critical Infrastructure
  - Power plants, communication centers
- Different Sensors
  - Acoustic, video or agitation
  - Data fusion
  - Wired connection
- Early Detection
  - Reduce false rate

Environment Monitoring

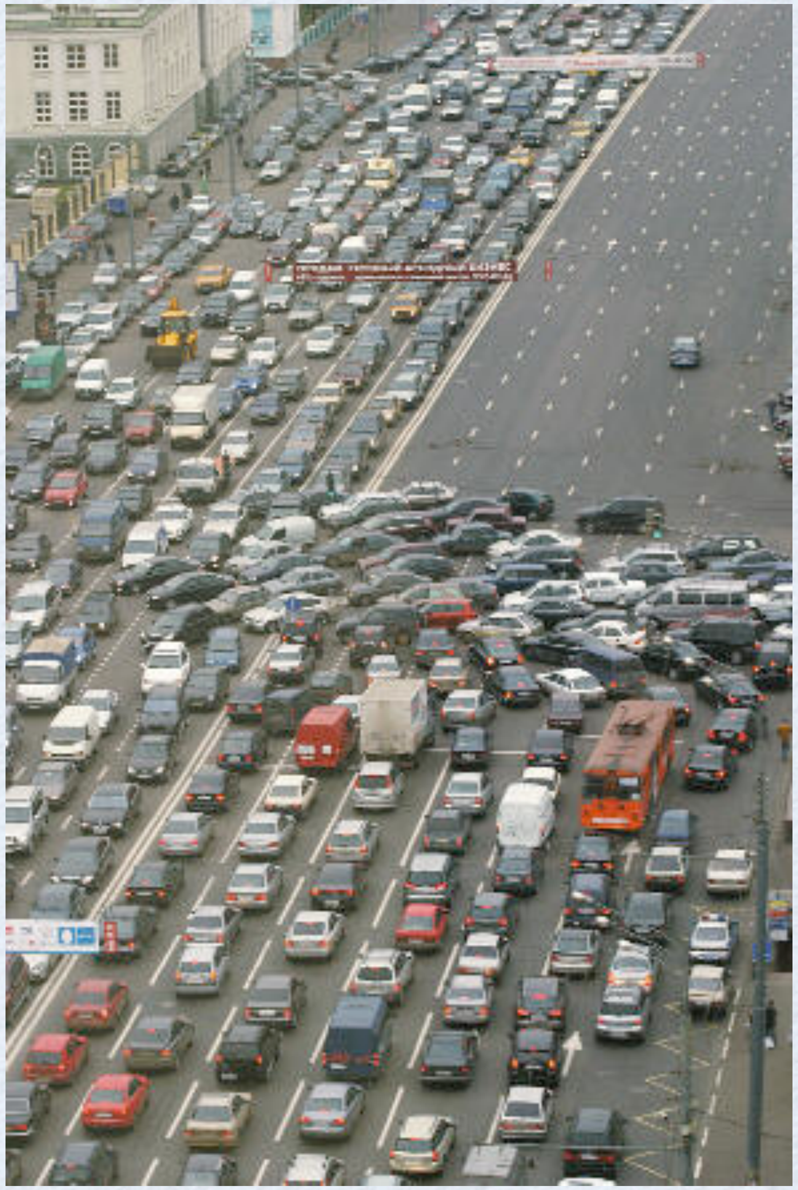
- Response to Climatic Trends
  - Temperature sensors, image sensors
  - Large regions to monitor
- Different Location of the Sensors
  - Space, air, ground
  - Different link speeds

Industrial Sensing

- Sensing and Maintenance
  - Aims at lower costs
- Wide Range of Sensors
  - Fluid level, vibration, and optical
  - pH probes, material properties
- Large Databases
  - 100 - 1000 sensors

Traffic Control

- Vehicle Traffic Monitoring
  - Detect vehicles / control traffic lights
  - Needs human operators
- Ad Hoc Networks
  - Deployed at every road intersection
  - Global traffic picture
- Sensors Attached to Vehicle
  - Privacy concerns



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Technical Problems

- Dynamic Environments
  - Energy and bandwidth constrains
- Challenges in Sensor Networks
  - Network discovery
  - Routing
  - Collaborative signal processing
  - Querying the database

Ad-Hoc Networks

- Planned Networks
  - *A priori* information of topology
  - Location of nodes
- Ad-Hoc Networks
  - Constructed in realtime, updated periodically
  - No global knowledge
  - Positioning algorithms

Network Routing

- Sensors operate autonomously
  - Change configuration
- Unreliable Communication Links
  - Redundancy and number of links
  - Size of the entire network
- Alternatives to Traditional Internet Protocol IP
  - No routing tables
  - Time, memory, and energy overhead

Collaborative Processing

- Data Fusion
  - Information sharing between nodes
  - Bandwidth - processing tradeoff
- Information from Multiple Paths
  - Fusion algorithm - avoid double counting
- Algorithms Attributes
  - Asynchronous due to varying processor speed
  - Cope with unreliable links

Security in Sensor Networks

- Hostile and Critical Environments
  - e.g. Power plants, communication centers
- Considered while Design
  - Reliable, fast, effective
- Network Security
  - Common attacks: Intrusion, spoofing

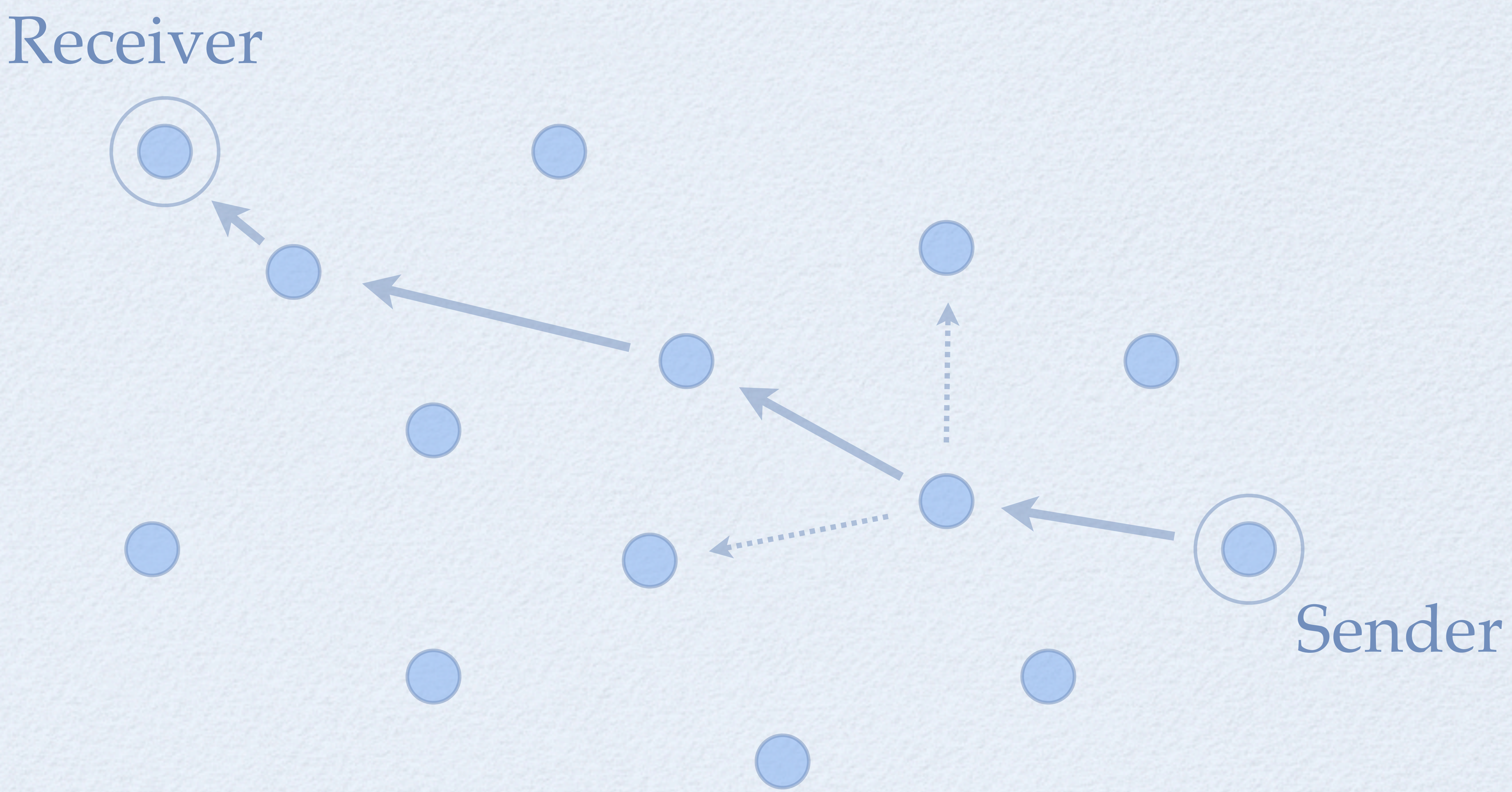
Research Results

- Localized Algorithms
- Distributed Tracking
- Classification in Sensor Networks

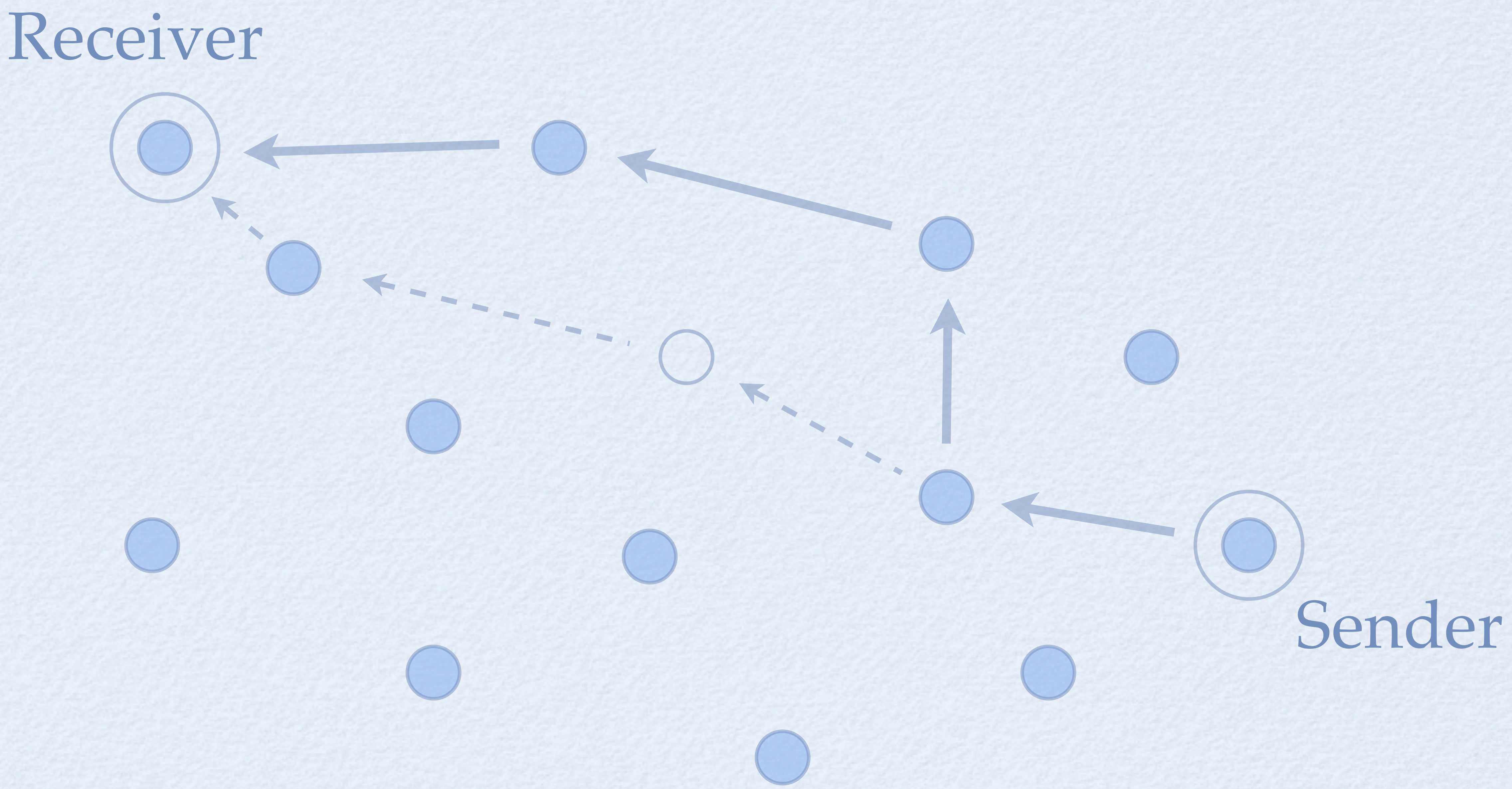
Algorithms and Diffusion

- Sensor Communication
  - Scales well - communication with neighbours
- Local Behaviour vs. Global Behaviour
  - Increasing network size
- Diffusion - Packet Forwarding
  - Specified direction or gradient

Algorithms and Diffusion



Algorithms and Diffusion



Algorithms and Diffusion

- Routing Information
  - Congestion, geographic information
    Power consumption, other resources
- Energy Issues
  - Half energy of flooding
  - 60% Energy compared to multicast
- No redundant Data, Eliminating Paths

Distributed Tracking

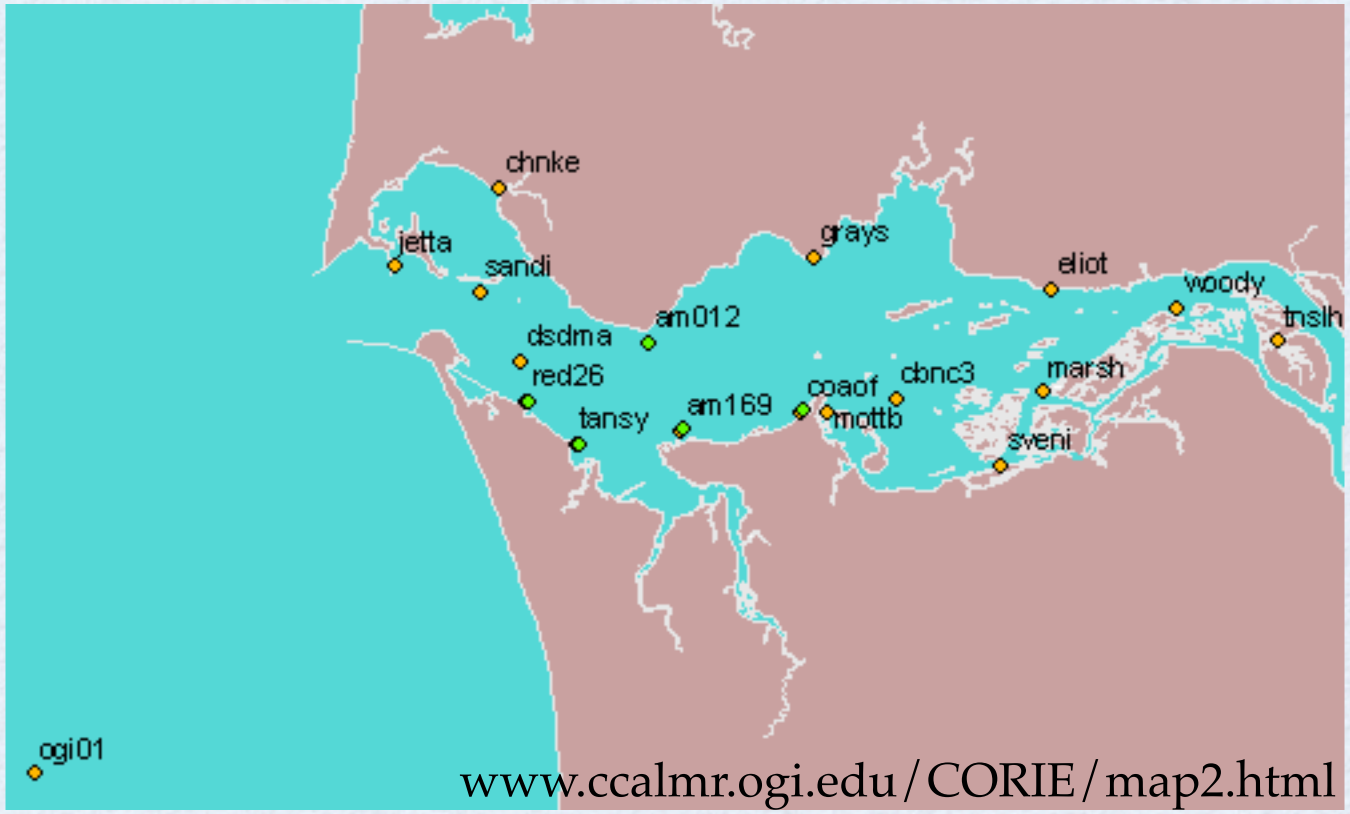
- Target tracking with large Networks
  - Collaboration and sharing
- Possible Approach
  - What to sense?
  - Communicate to whom?
- Resource constrains
  - Controls information sharing

Mobile Agents

- Agent Paradigm
  - Smart and independent programs
- Code moved to Sensors
  - Integration or fusion
- Performance
  - Agent data smaller in size than actual data
  - Safe bandwidth

CORIE

- Environmental Observation and Forecasting System
  - **Co**lumbia **Ri**ver



www.ccalmr.ogi.edu/CORIE/map2.html

CORIE

- Communication Networks
  - To receiver on-shore - wireless
  - To centralized compute-farm - wired via T1 link
- Measurements
  - Flow field velocity, salinity
  - Temperature, and water levels
- Power Supply
  - Electric grid or photovoltaic power

CORIE

CORIE

- Computation Models
  - 2D, 3D models of water circulation
- Nowcast
  - Current conditions over different areas
- Forecast
  - Flow velocity or water depth

CORIE

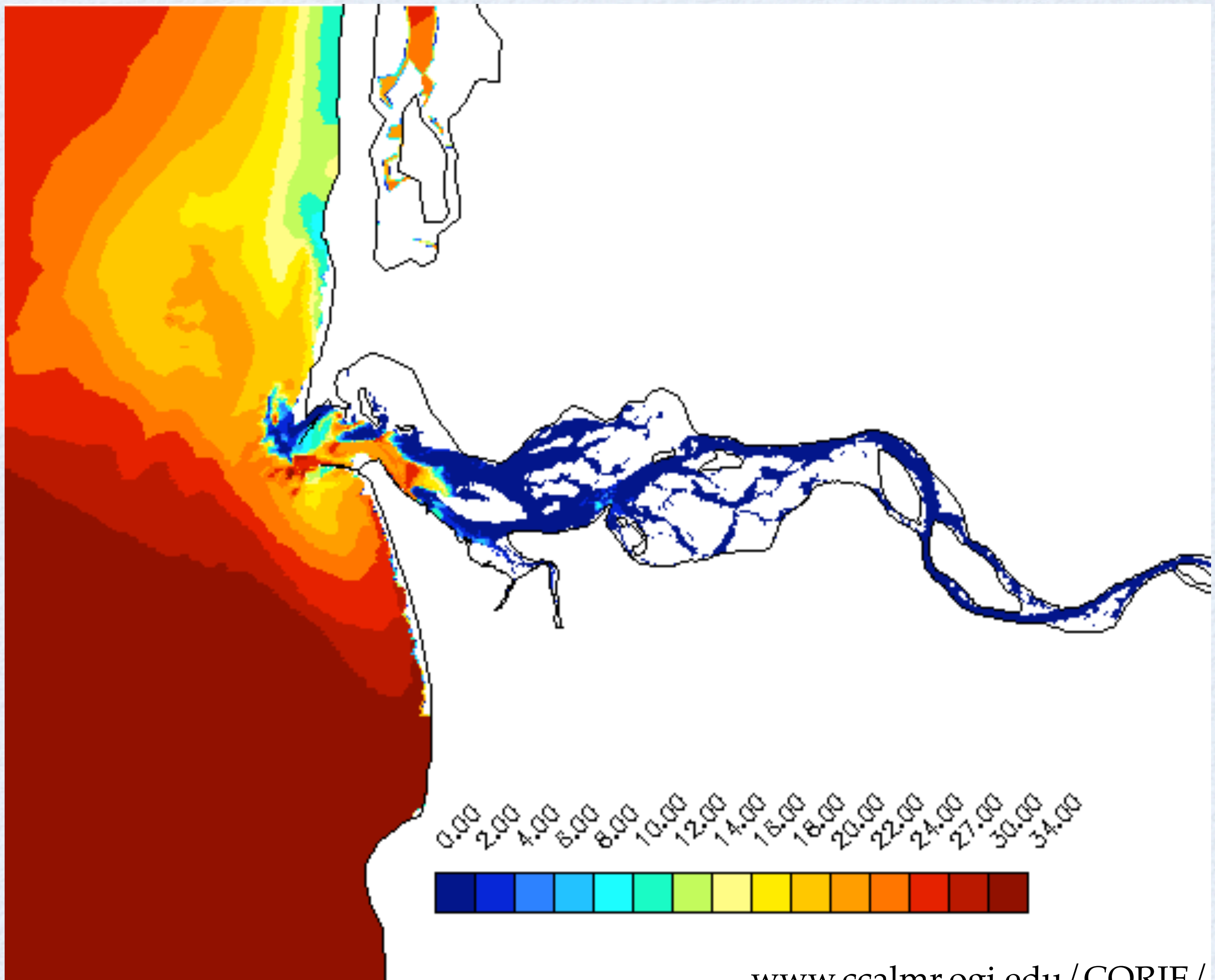
- Autonomous Mobility
  - Stations are fixed in locations
  - Vessels too expensive and inefficient
  - Could follow physical processes
- Time and Location Dependence
  - Sampling in time and space
  - Change protocols on local or remote information

CORIE

CORIE

- Reactive Behaviour
  - Events in different regions affect other regions
  - *e.g.* Tsunami detection off-shore
- Sensor's Response
  - Reprogrammed automatically
  - Tight time constrains
  - *e.g.* Sample at higher frequencies

CORIE



www.ccalmr.ogi.edu/CORIE/

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