# Sextant: A Unified Node and Event Localization Framework Using Non-Convex Constraints

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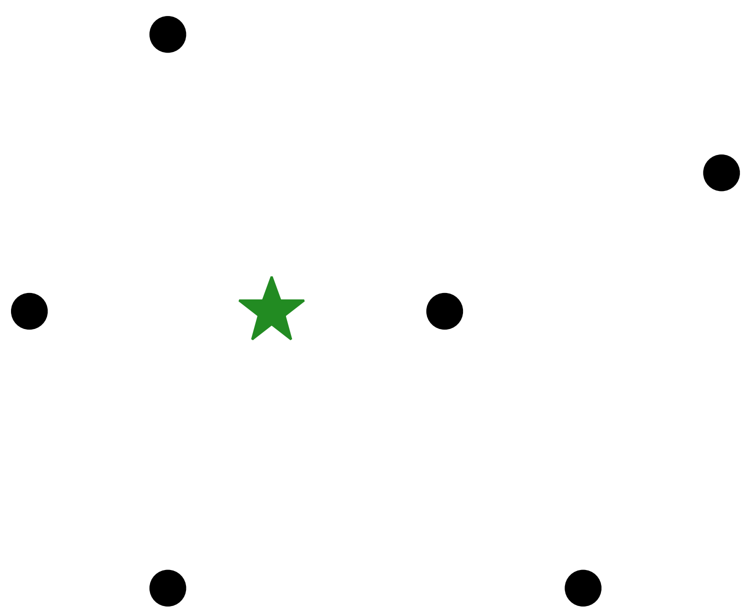
# Challenges in Localization



### Hardware

- Expensive
- Power Consuming

### Infrastructure

- Initial setup required
- Not always available

### Modeling

- Irregular wireless coverage area
- Introduces error

# Sextant Approach

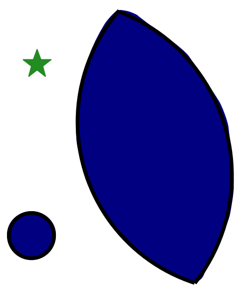
- Extract geometric constraints
- Disseminate them transitively
- Solve in a distributed manner

# Sextant Approach

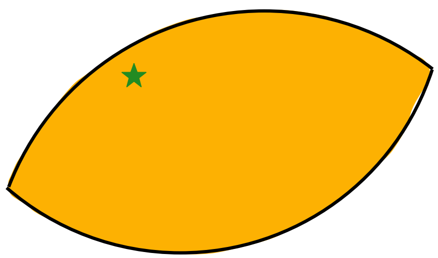
## Contributions

- Unified Node and Event localization
- Accurate
  - Negative as well as positive information
  - Explicit representation
- Practical
  - Constraint extraction
  - Deployed on MICA-2 motes, laptops and PDAs

# Sextant Approach



Negative constraint



Positive constraint

## Contributions

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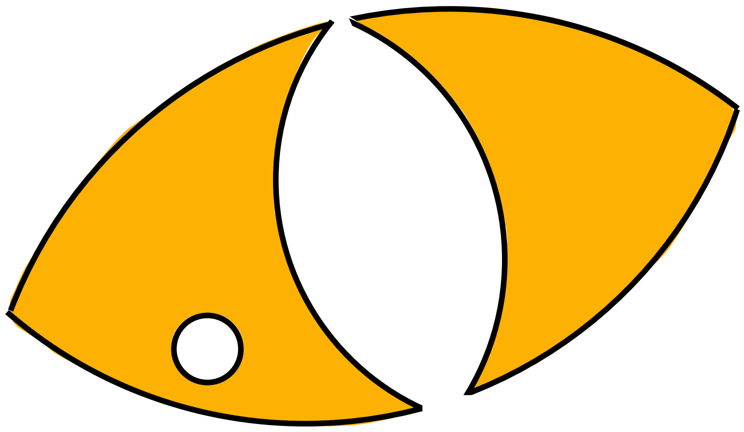

- Need not be convex
- May have holes
- May have disconnected components

## Contributions

- Unified Node and Event localization
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- Practical
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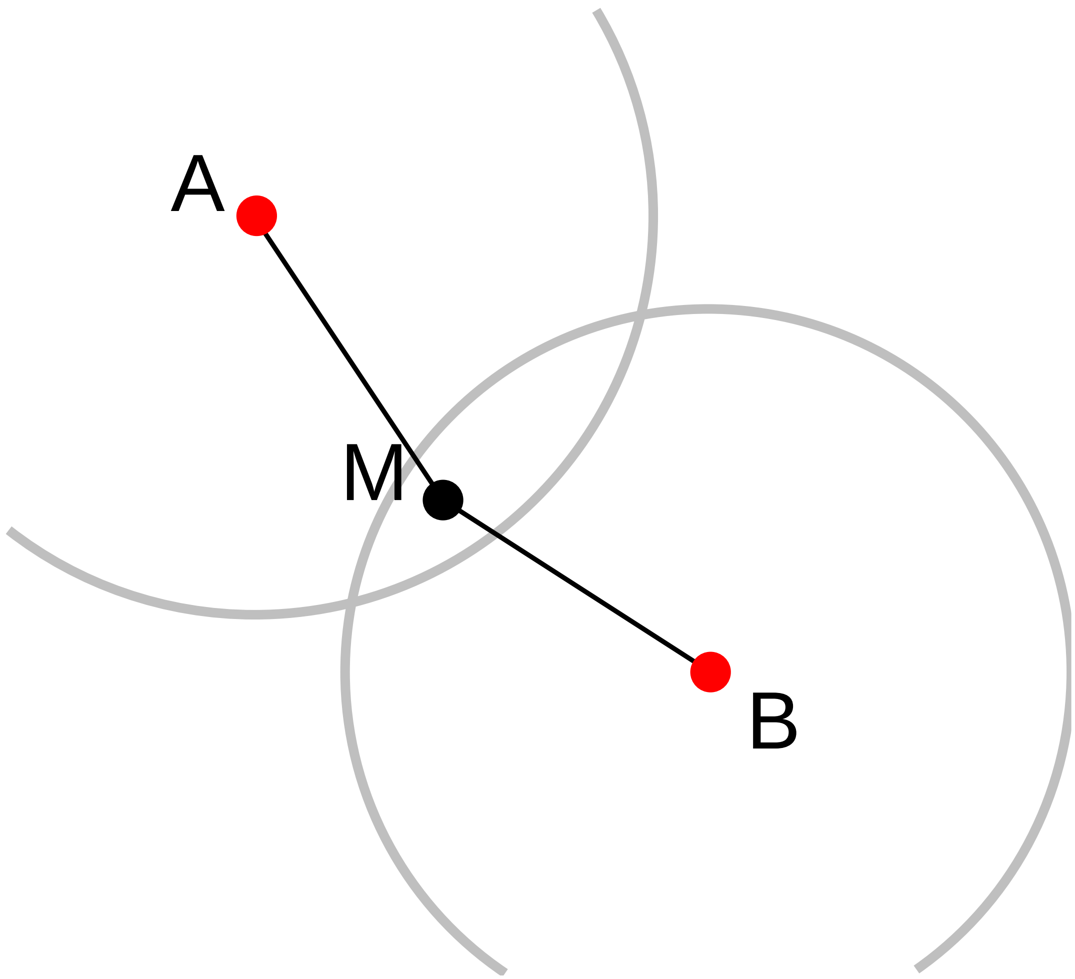
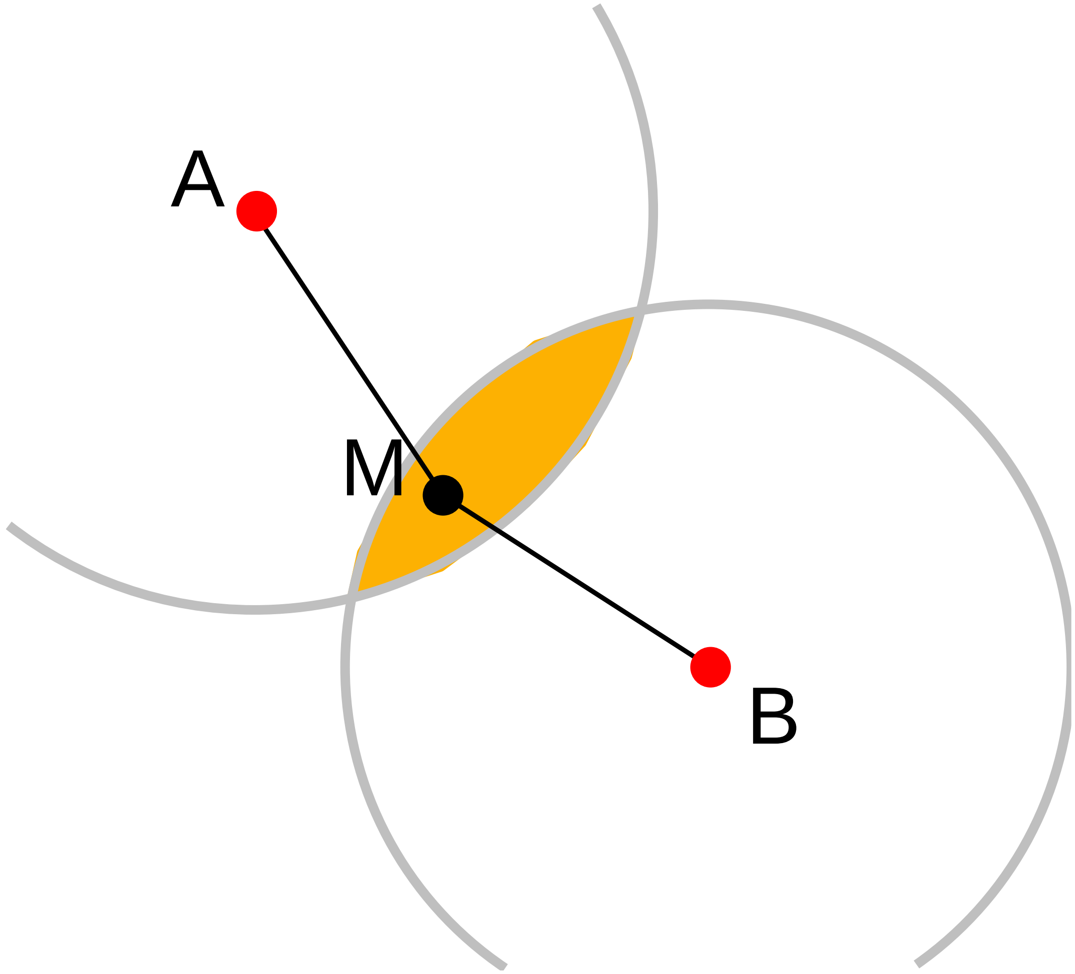
# Node Localization

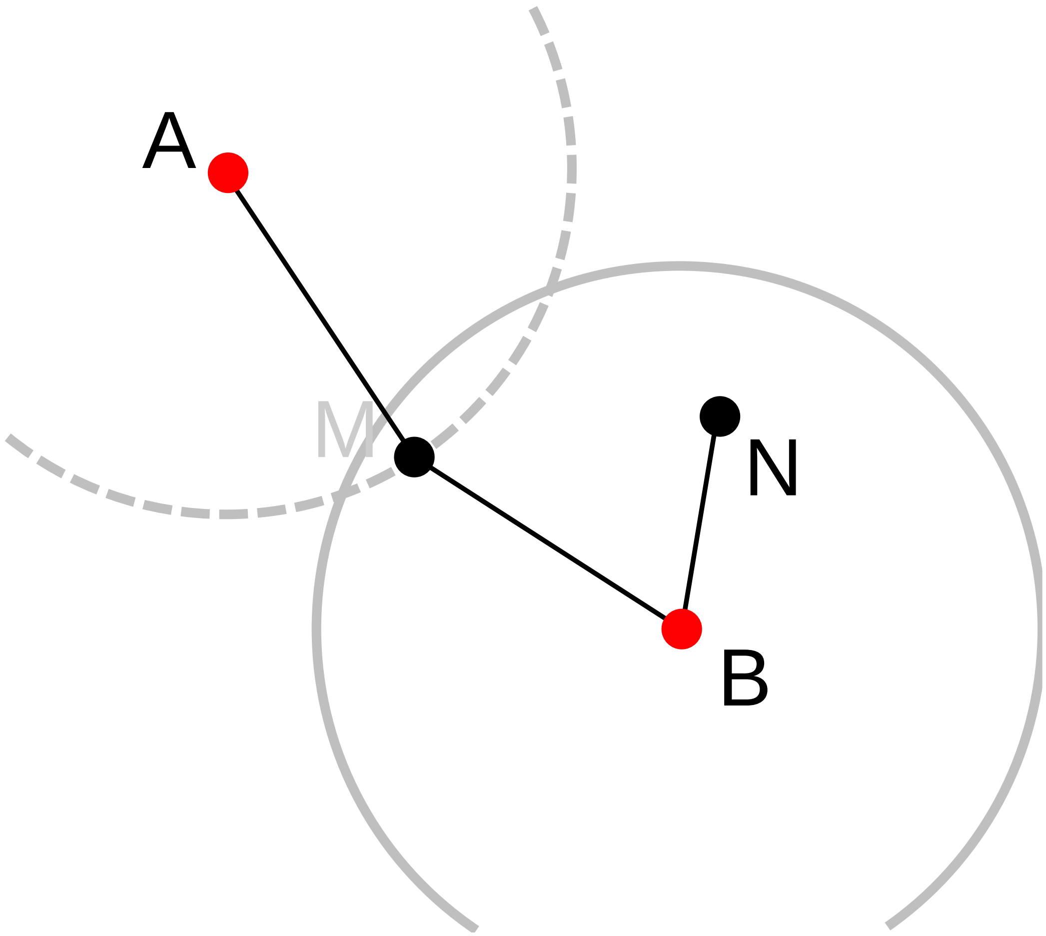



Positive Information

# Node Localization

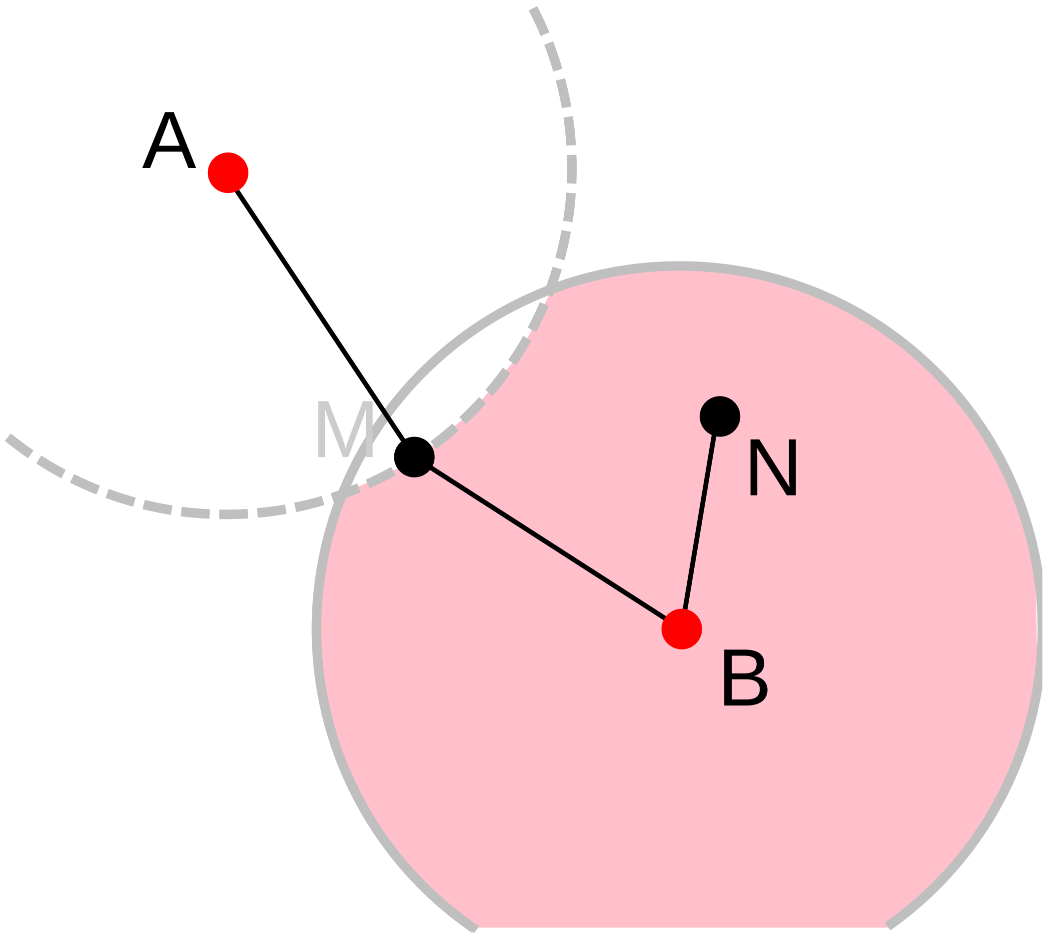



Intersection of Positive Information

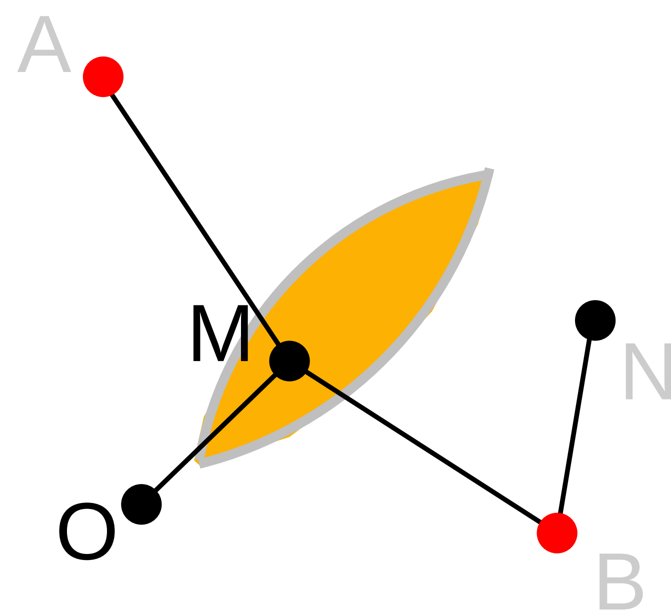



Negative Information

# Node Localization

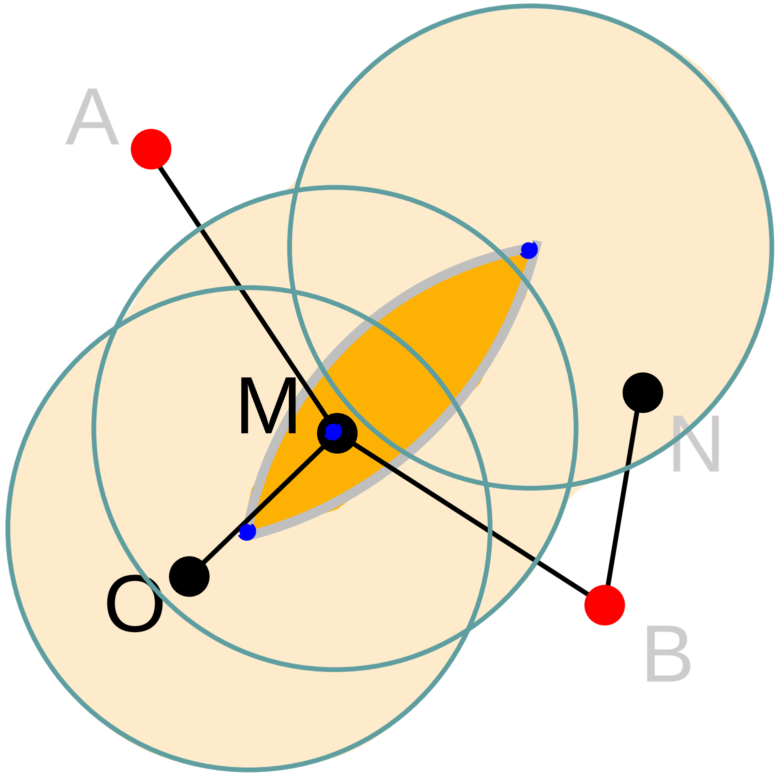



Subtraction of Negative Information



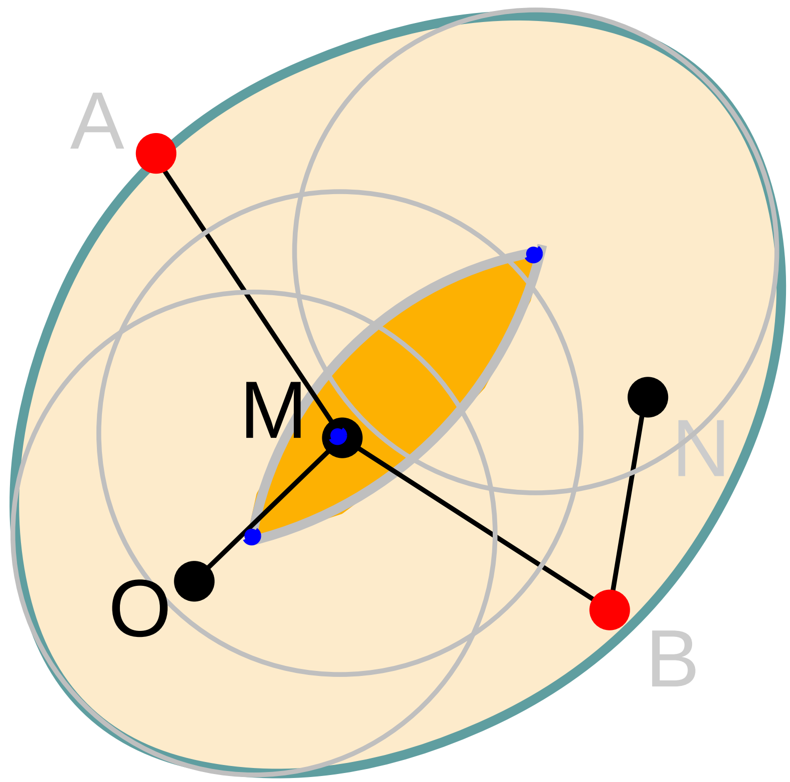

Transitive Dissemination of Positive Information

# Node Localization




Transitive Dissemination of Positive Information

# Node Localization

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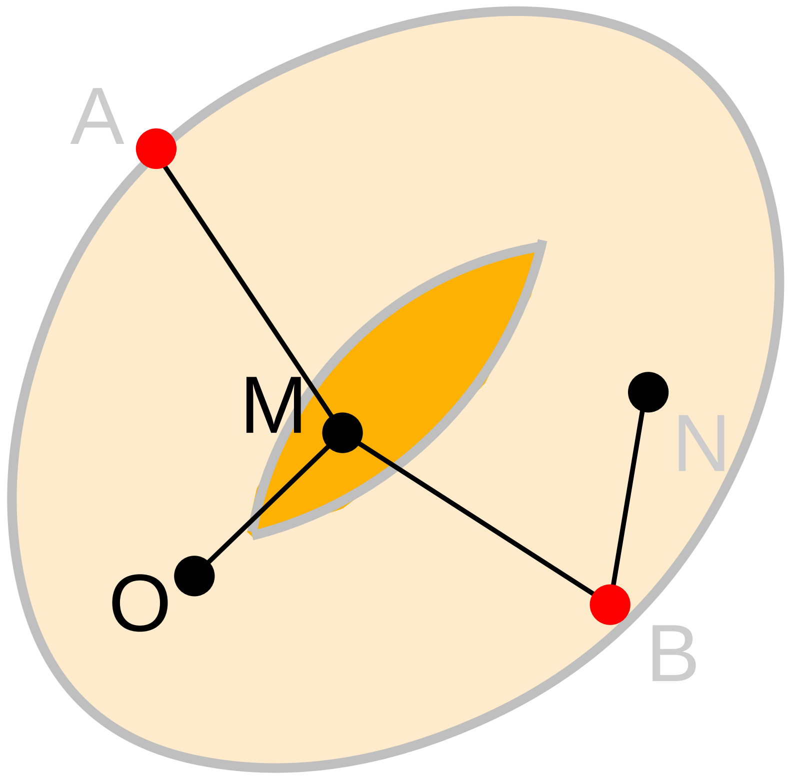


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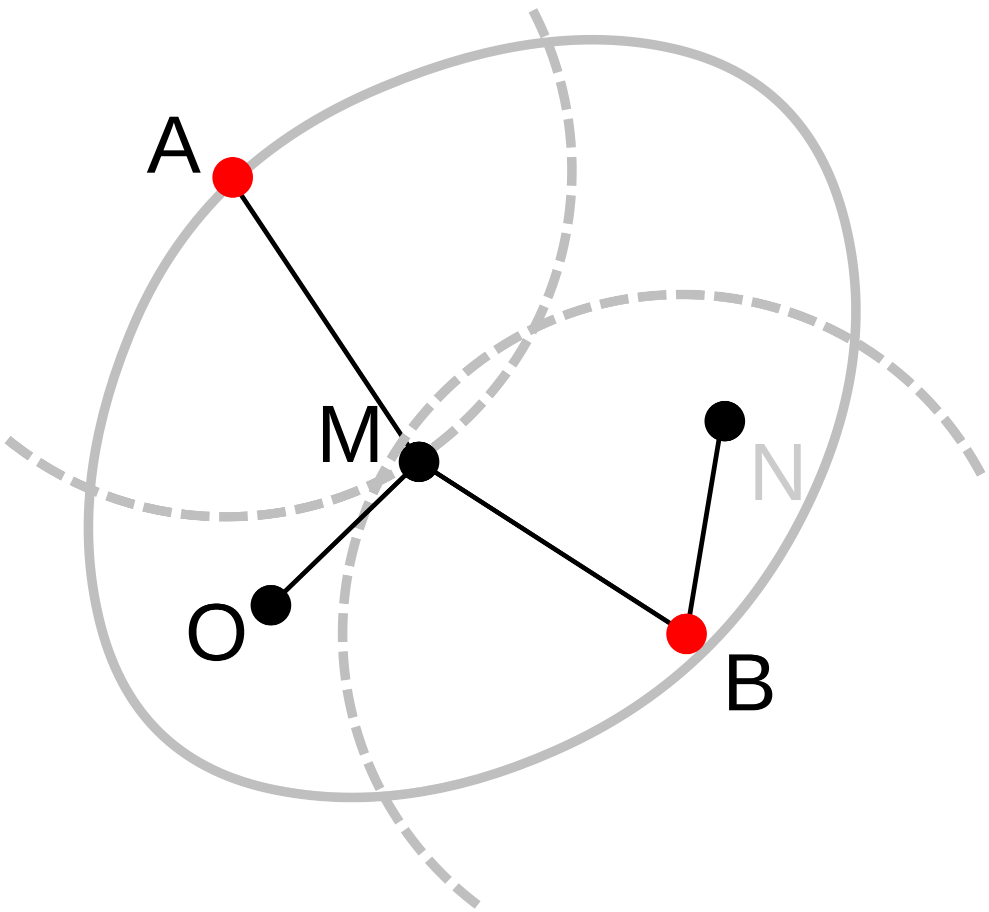
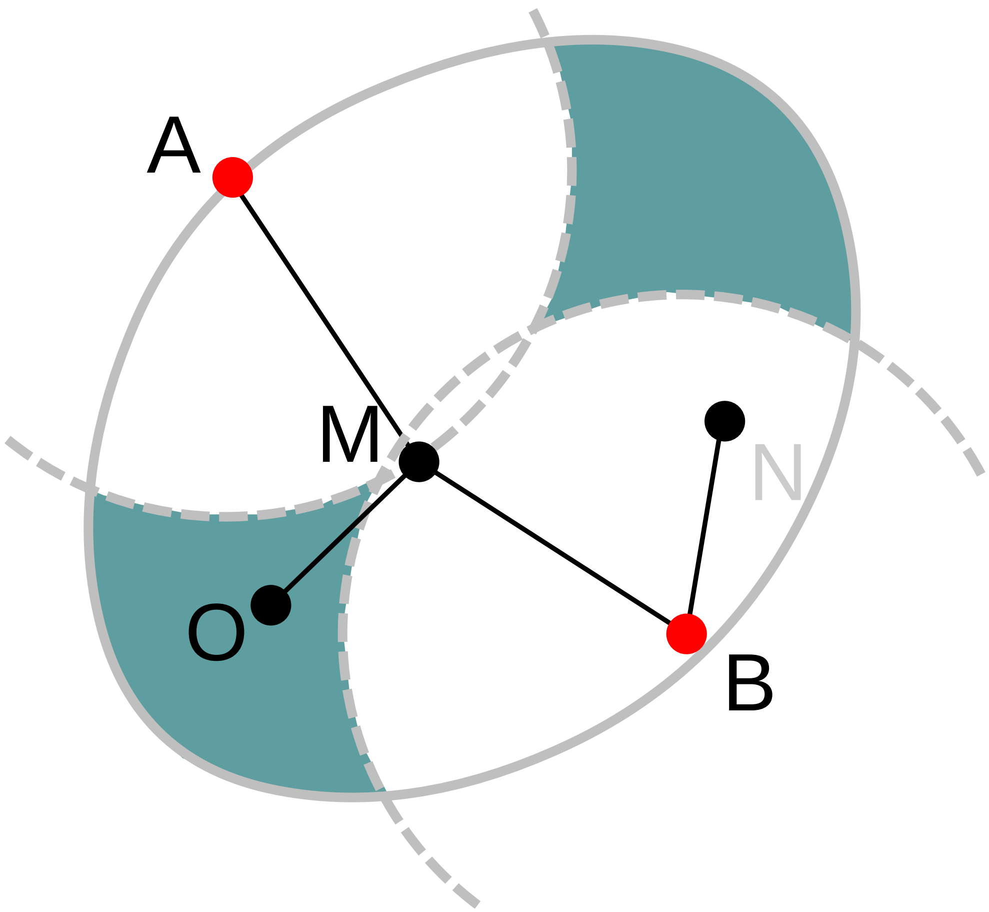
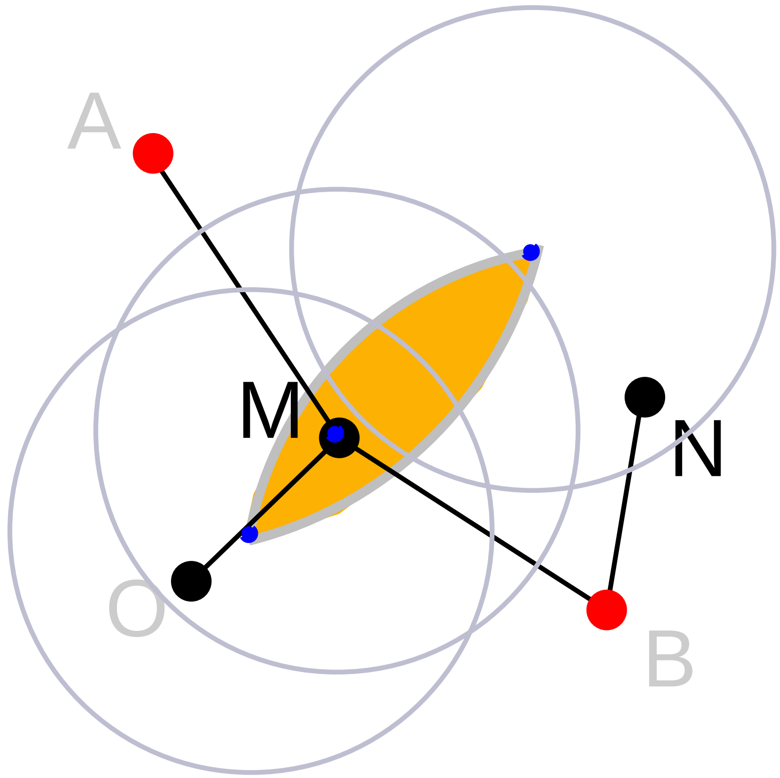



Combining Positive and Negative Information

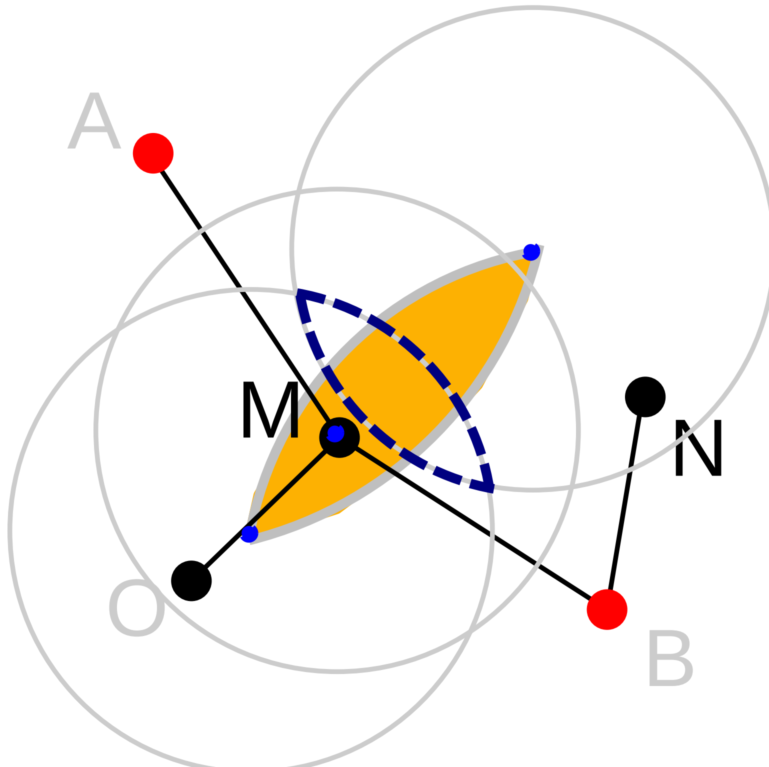
# Node Localization




Combining Positive and Negative Information

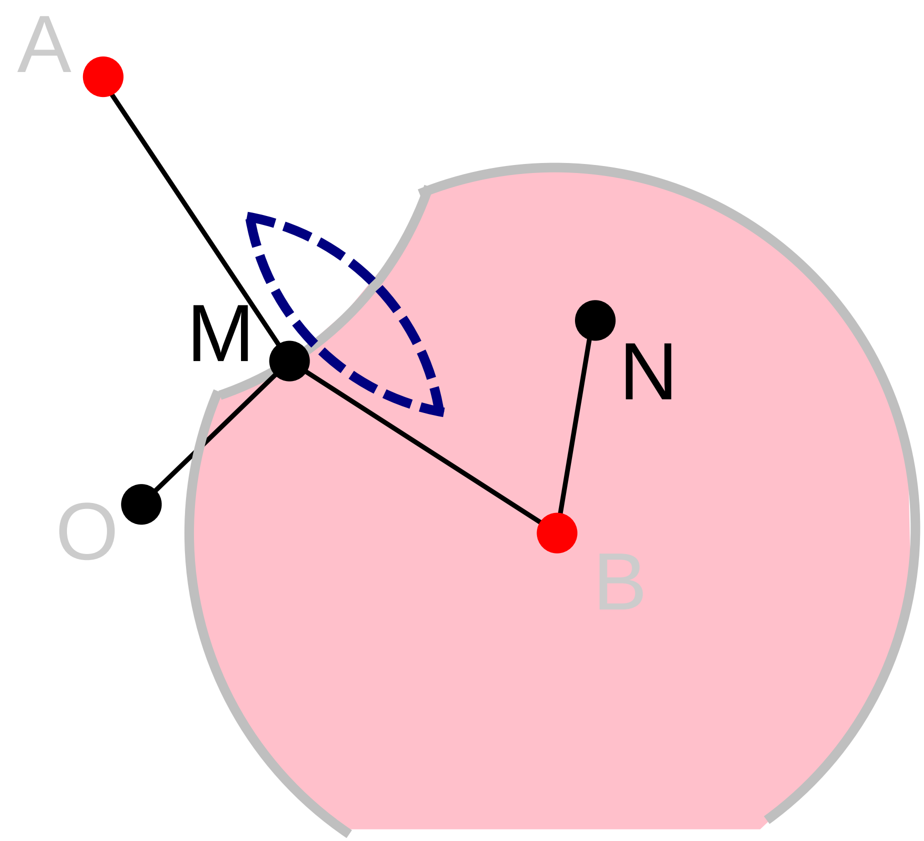



Transitive Dissemination of Negative Information



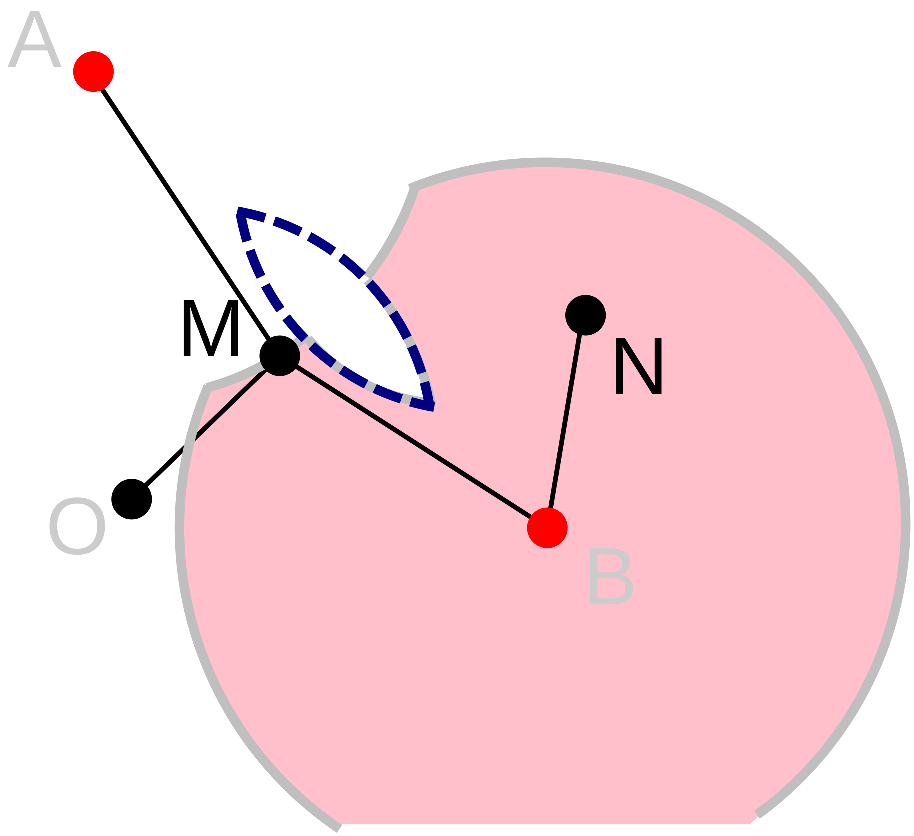

Transitive Dissemination of Negative Information

# Node Localization



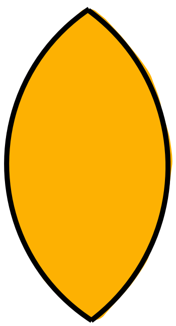

Refining Location Estimates

# Node Localization




Refining Location Estimates

# Sextant Approach



Polygons with Bézier boundaries

## Each Node $x$

- Location Estimate: $\mathcal{E}_x$
- Positive Constraint: $\mathcal{P}_x$
- Negative Constraint: $\mathcal{N}_x$
- Set of positive constraints: $\Gamma_x$
- Set of negative constraints: $\Theta_x$

## Invariant

$$\mathcal{E}_x = \bigcap_{p \in \Gamma_x} p \setminus \bigcup_{n \in \Theta_x} n$$

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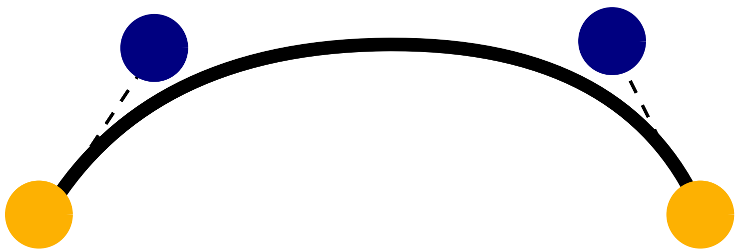
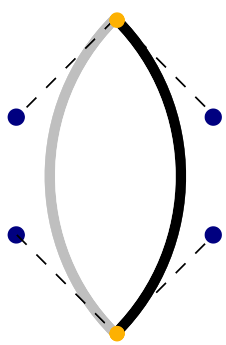


Bézier curve



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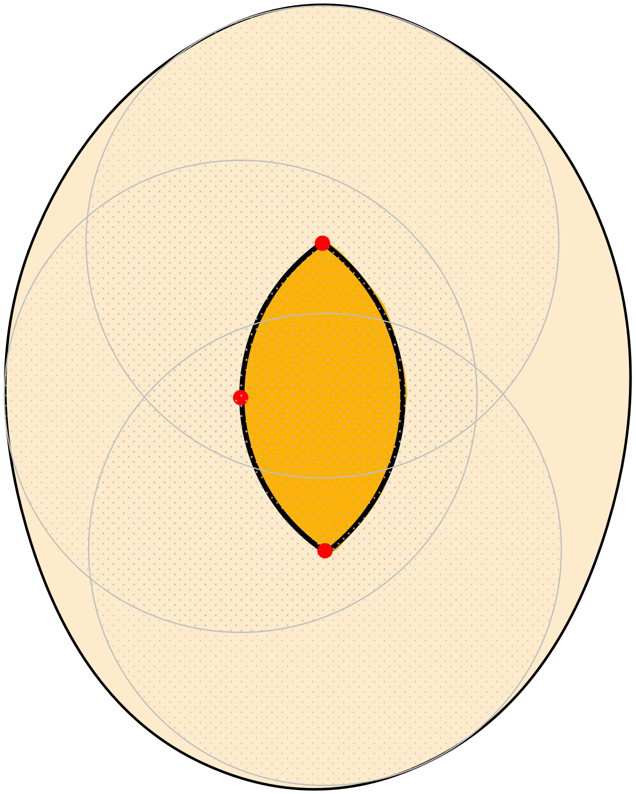

Union of circles in $\mathcal{E}_x$

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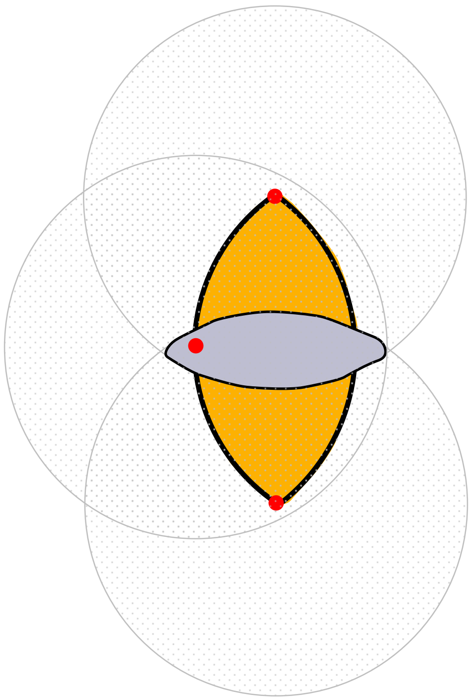

Intersection of circles in $\mathcal{E}_x$

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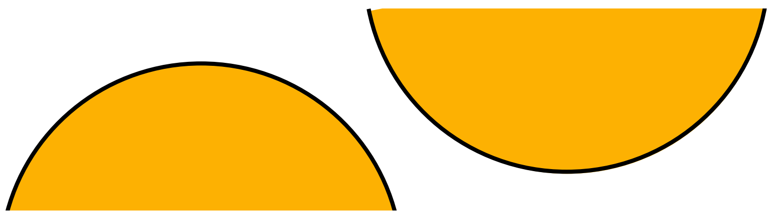
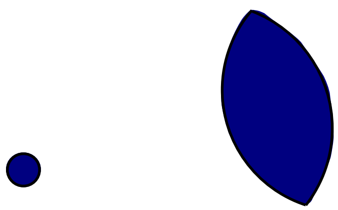


$\Gamma_x$: learned from wireless neighbors



$\Theta_x$: learned from wireless non-neighbors

**Each Node $x$**

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**Invariant**

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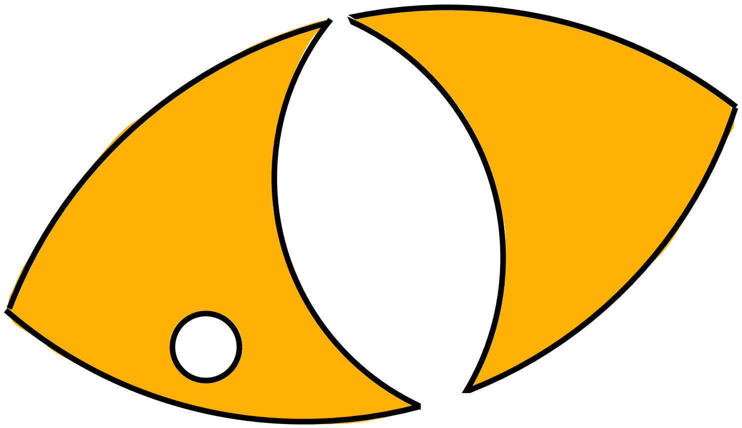
# Sextant Approach



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### Invariant

$$\mathcal{E}_x = \bigcap_{p \in \Gamma_x} p \setminus \bigcup_{n \in \Theta_x} n$$

# Event Localization

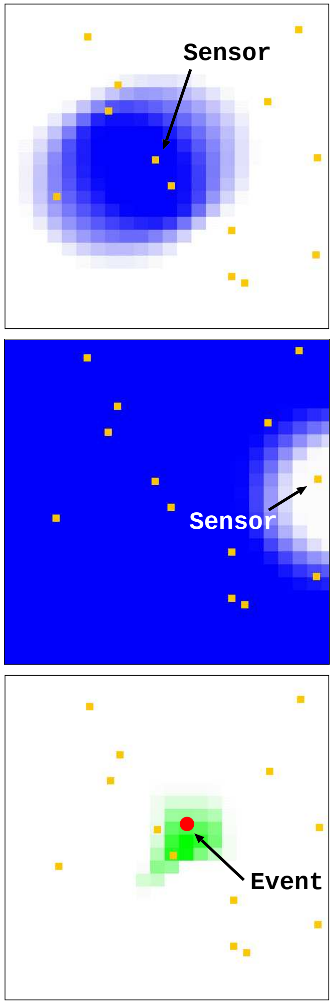
### Similarity to Node Localization

- Constraints from sensing hardware vs. wireless radio
- Boolean sensed/not-sensed signal vs. boolean connectivity

### Differences from Node Localization

- Annotate resultant areas with probabilities

# Event Localization




Bayesian Probability

## Positive Contribution

Sensor somewhere in $\mathcal{E}$ detects event; probability event in grid $\mathcal{G}_i$.

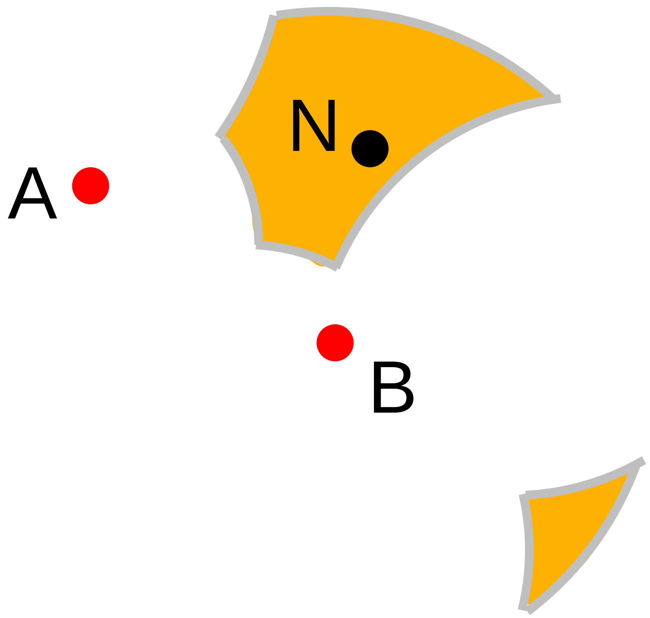
## Negative Contribution

Sensor somewhere in $\mathcal{E}$ does not detect event; probability event in grid $\mathcal{G}_i$.

## Solution

Product of positive and negative contributions from sensors sensing and not-sensing the event.

# Feedback



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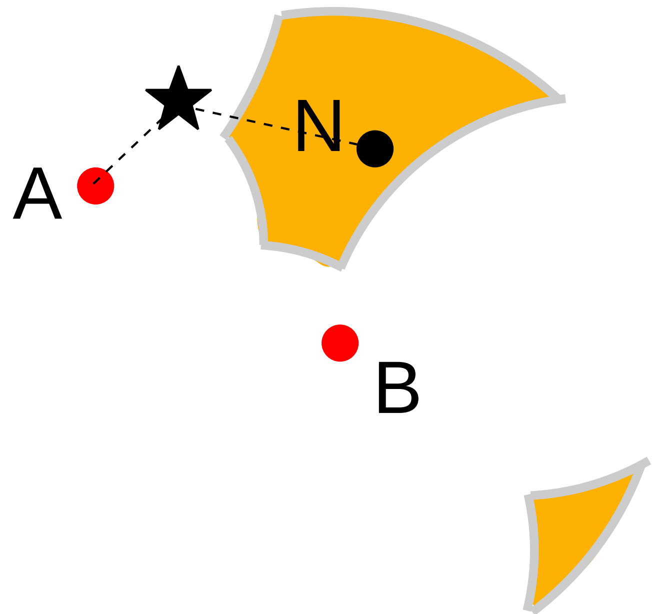

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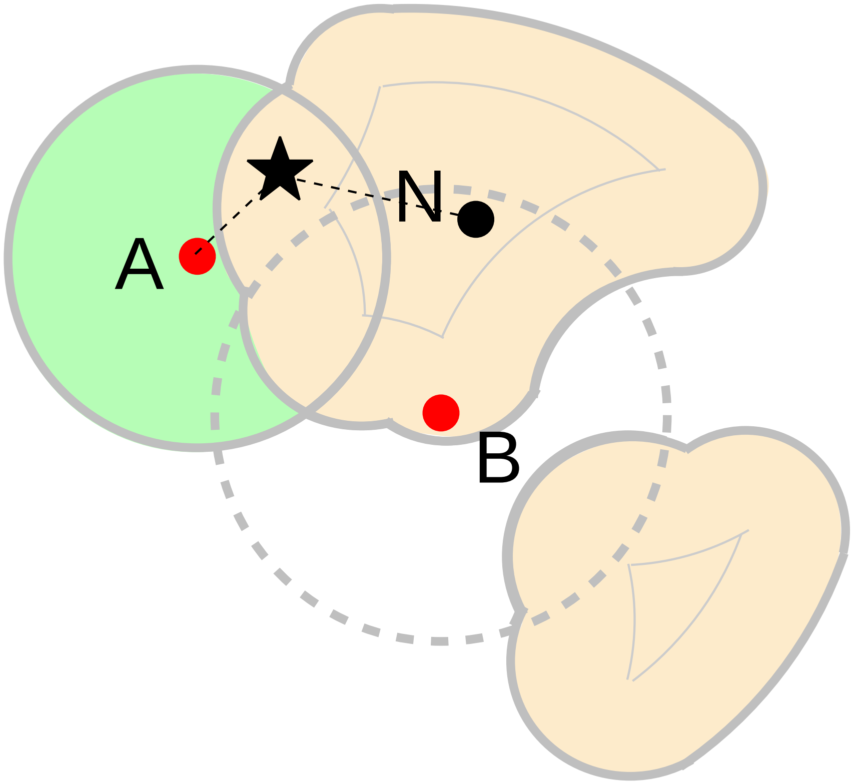

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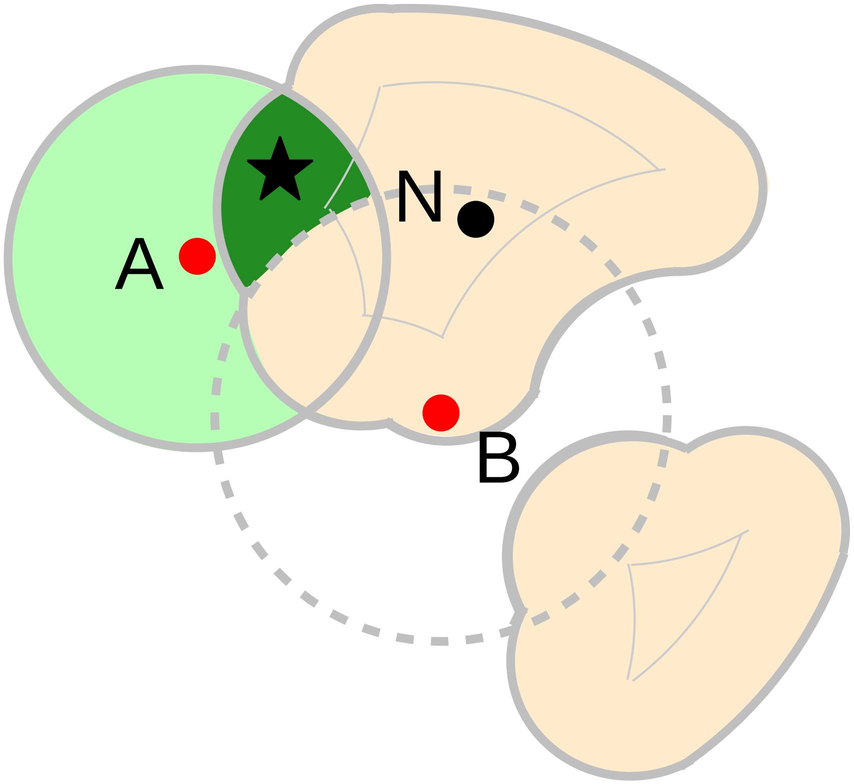

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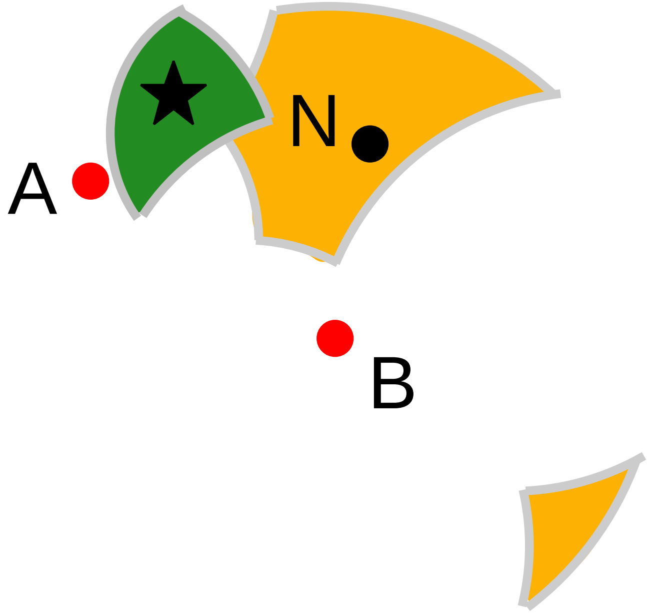

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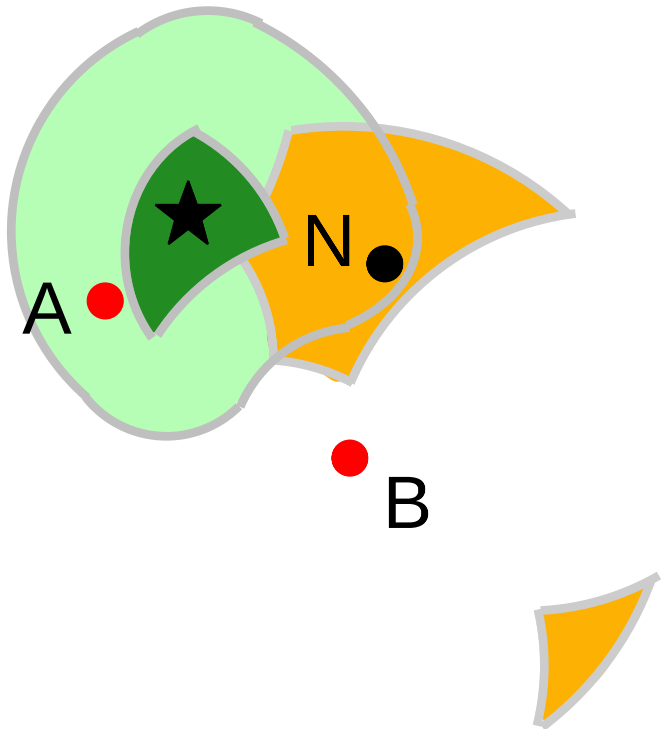


Events as a Source of Constraints

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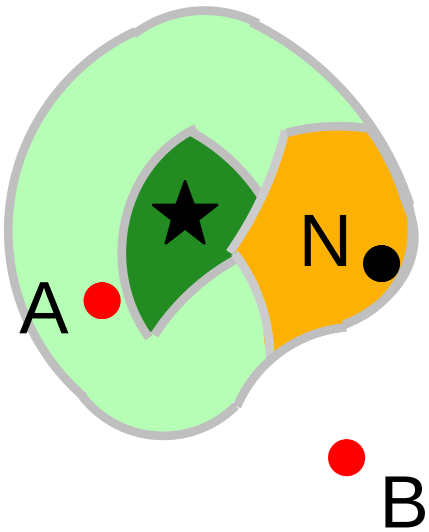
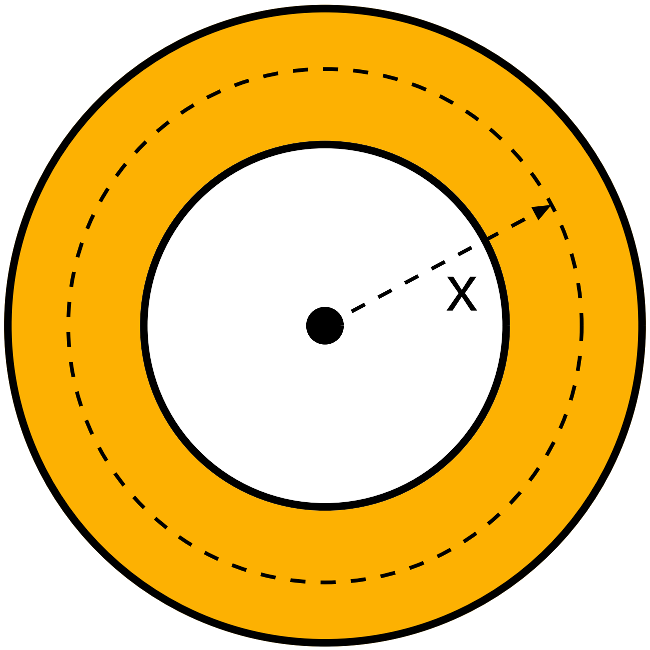



Events as a Source of Constraints

# Optimizations




Annulus for range $x$

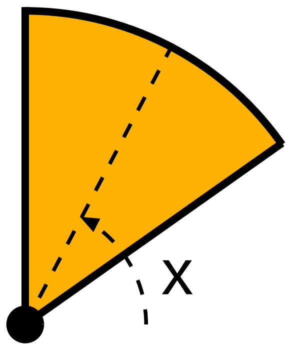
**Wireless Hardware**

- Range Measurements
- Angle of Arrival

**Sensor Hardware**

- Event Distance
- Directional Sensors

# Optimizations




Sector for angle $x$

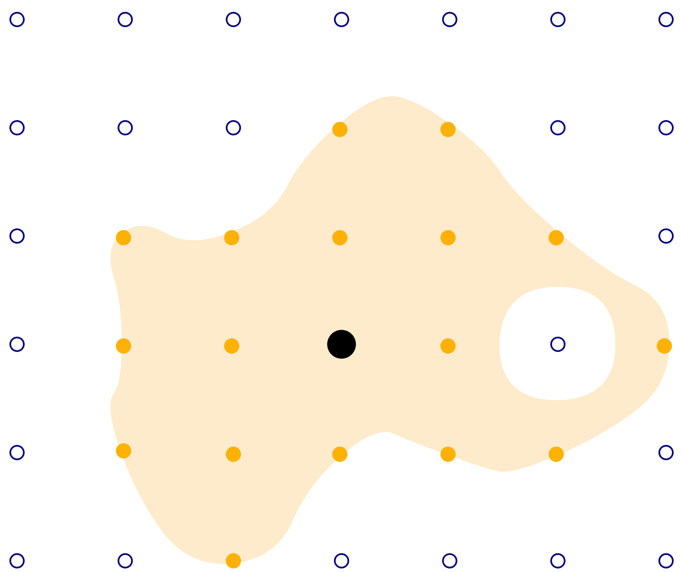
### Wireless Hardware

- Range Measurements
- Angle of Arrival

### Sensor Hardware

- Event Distance
- Directional Sensors

# Modeling



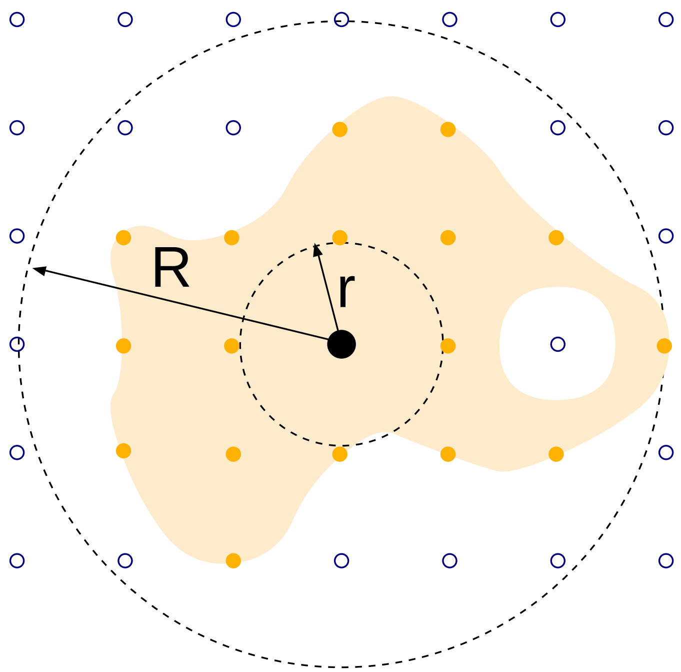
Wireless coverage area is non-convex and has holes

### Wireless Radio

Boolean packet-received / packet-not-received.

- All reachable nodes $\leq R$ away
- All unreachable nodes $\geq r$ away

# Modeling




## Wireless Radio

Boolean packet-received / packet-not-received.

- All reachable nodes $\leq R$ away
- All unreachable nodes $\geq r$ away

# Protocol

## Neighborhood Discovery

- Nodes transmit periodic beacons
- Threshold beacon reception required for boolean connectivity

## Gossip

Disseminate constraints as long as they are useful

- Positive information – used only at first hop
- Negative information – used within the first few hops

# Validation of Node Localization

## Implementation

- Implemented on MICA-2 motes, laptops and PDA
- About 2kB of storage per node
- About 80kB data transmitted per node until convergence

## Setup

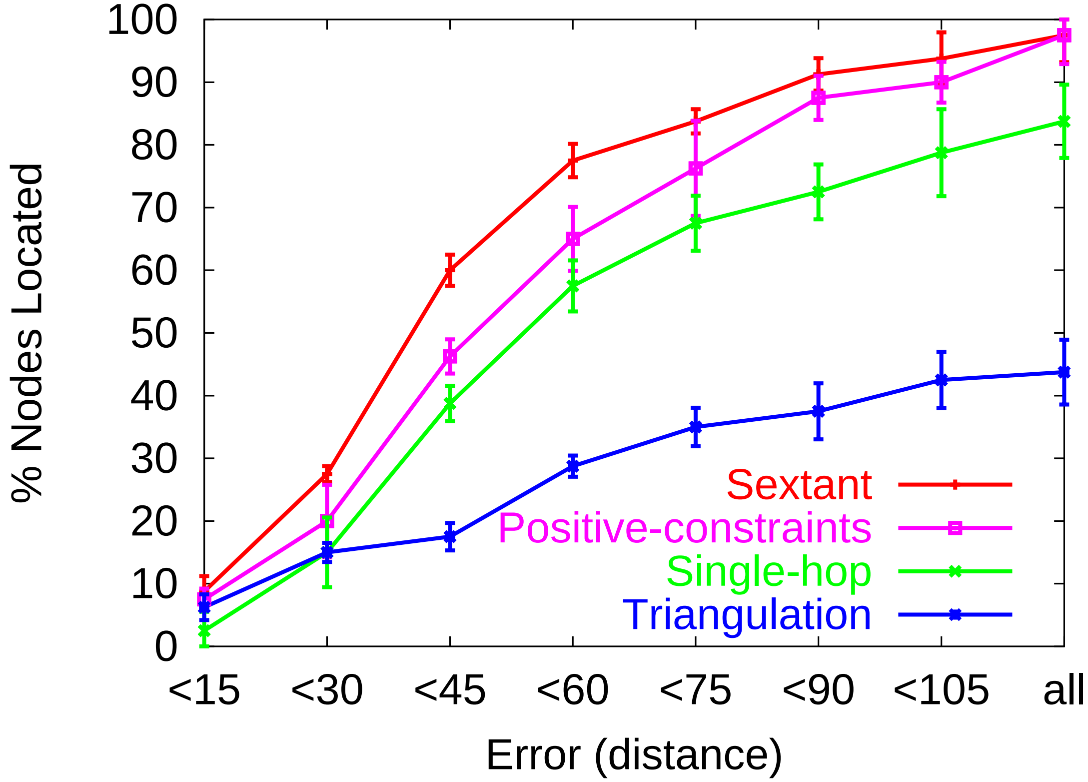
- 50 MICA2 motes placed in a grid pattern
- Landmarks chosen at random
- 80% packet reception threshold chosen for connectivity

# Validation of Node Localization

## Comparing Node Localization

- **Triangulation** – Centroid of neighbor nodes
  - GPSLess
- **Single-hop** – No transitive dissemination
  - Active Badge, Cricket, GPSLess, Localization Using Moving Target
- **Positive-constraints** – No negative information
  - APS, Convex position estimation, N-hop Multilateration, Robust Positioning
- **Sextant**

# Validation of Node Localization

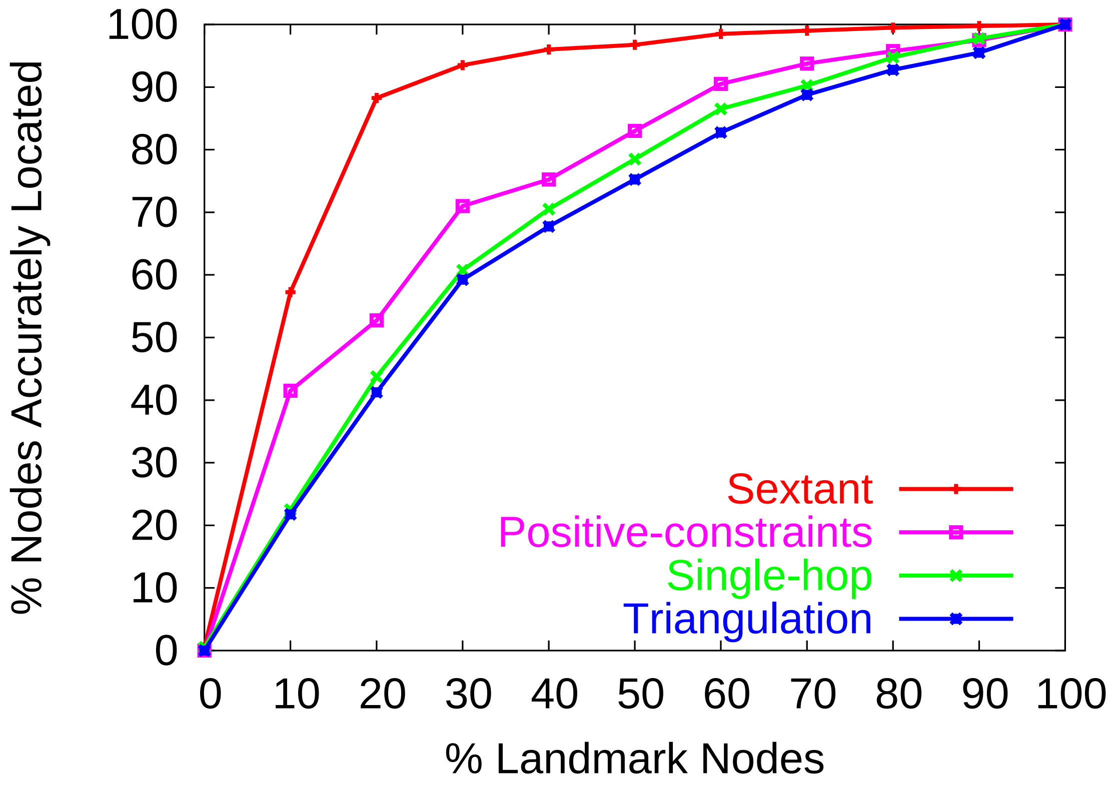



## Node Localization

- Accurate
- Efficient
- Scalable

Sextant locates more nodes accurately

# Validation of Node Localization

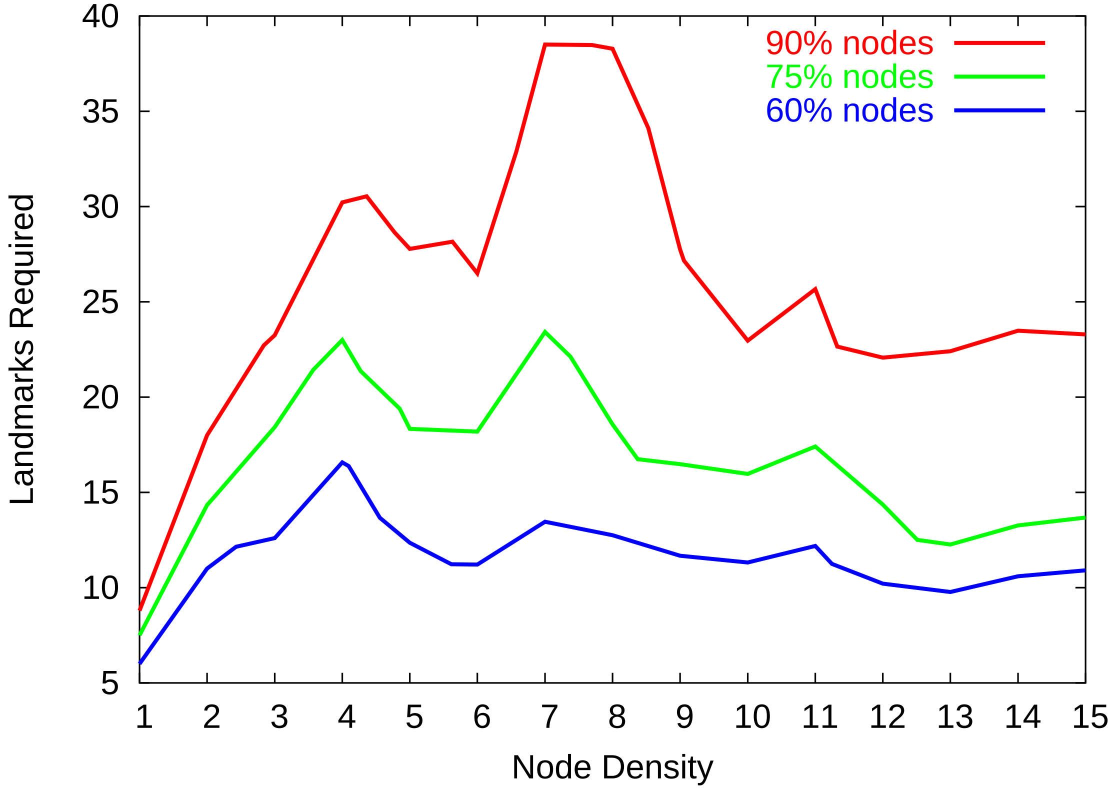



## Node Localization

- Accurate
- Efficient
- Scalable

Sextant requires few landmarks

# Validation of Node Localization




Sextant requires fixed landmark density

**Node Localization**

- Accurate
- Efficient
- Scalable

# Validation of Event Localization

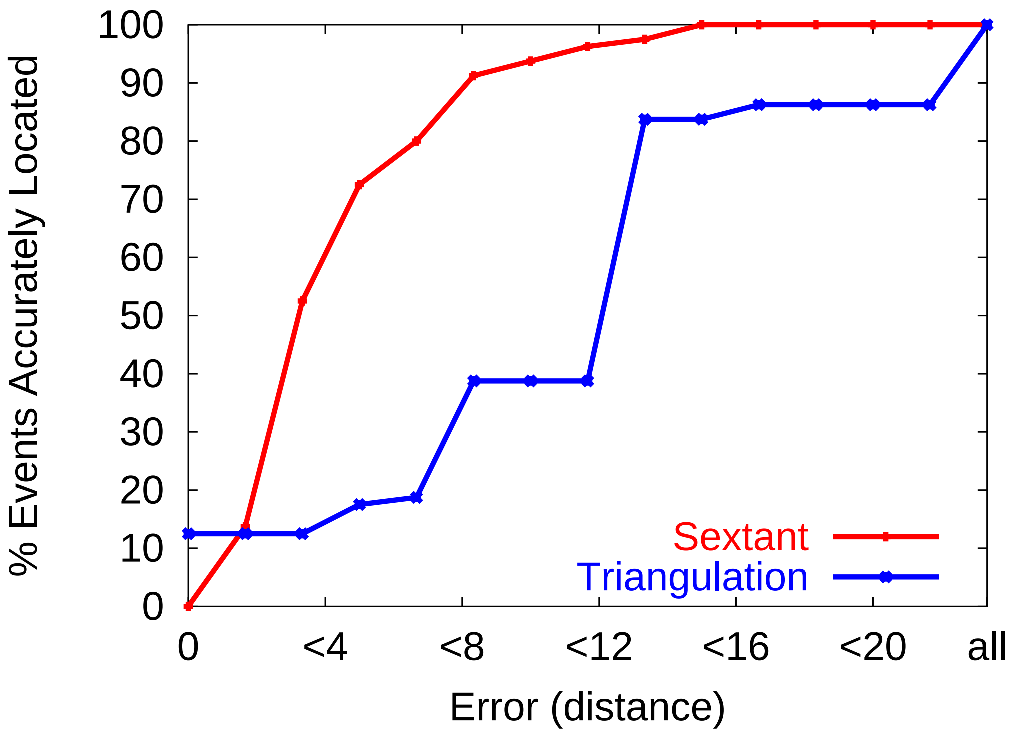
## Setup

- 50 MICA2 motes placed in a grid pattern
- Event is a flash of light
- Appreciable change in analog value triggers sensor

## Comparing Event Localization

- **Triangulation** – Centroid of sensors reporting the event
    - Acoustic Ranging
- **Sextant**

# Validation of Event Localization




**Event Localization**

- Accurate
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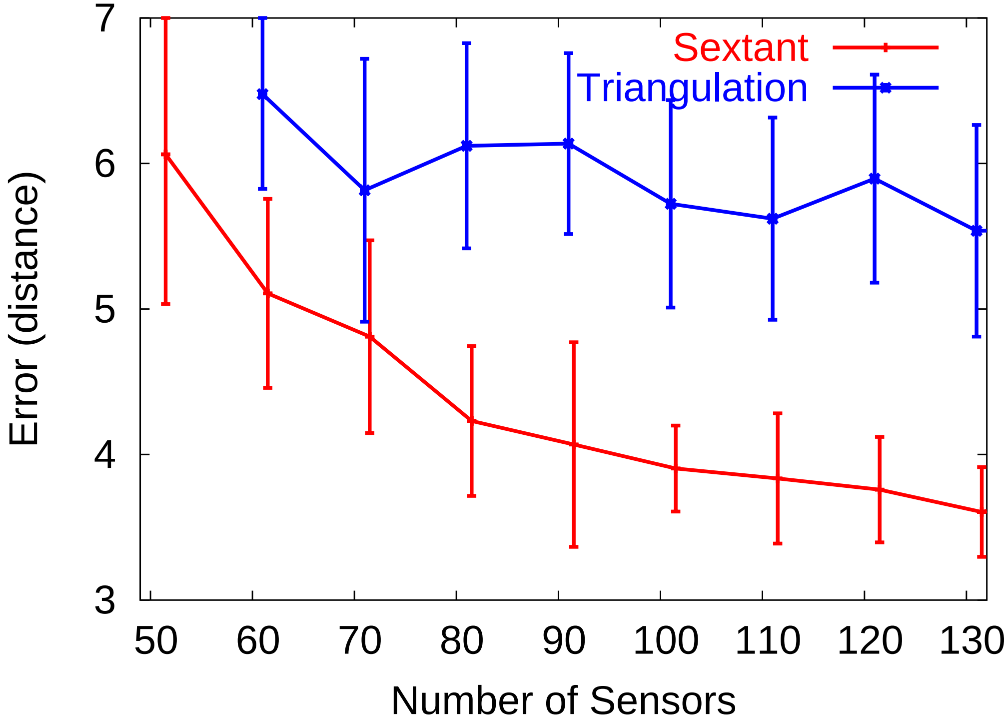
Sextant locates more events accurately

# Validation of Event Localization

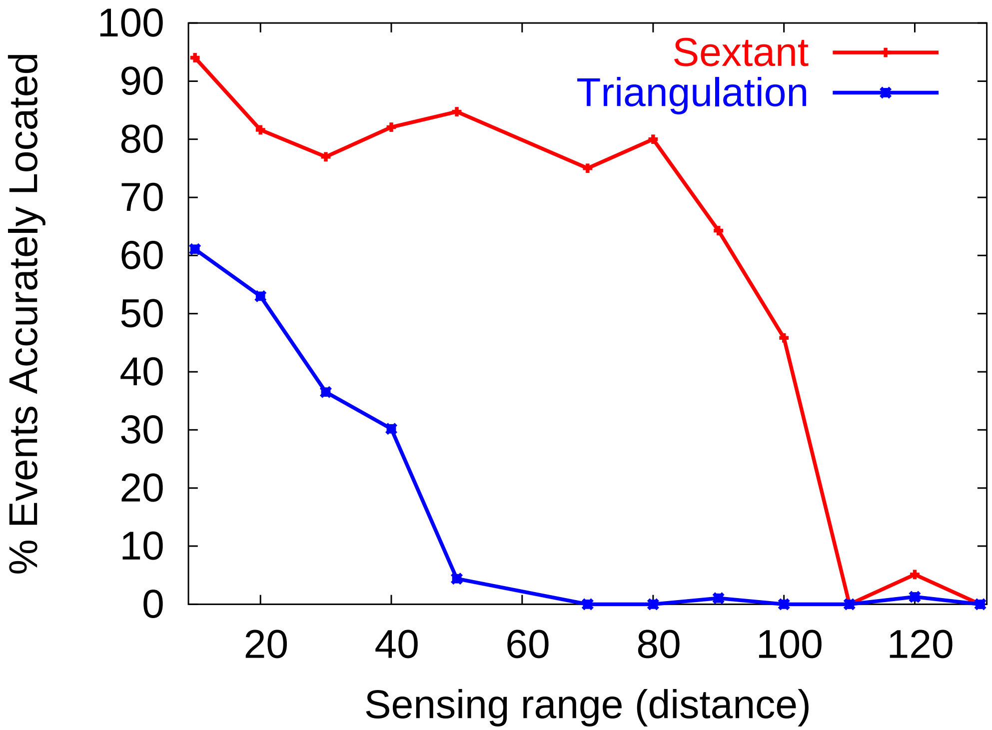



Accuracy improves with nodes

**Event Localization**

- Accurate
- Efficient
- Robust

# Validation of Event Localization




Sextant independent of sensing range

## Event Localization

- Accurate
- Efficient
- Robust

# Summary

- Sextant unifies node and event localization in the same framework
- Sextant achieves high accuracy and scalability
  - Explicit representation of regions using Bézier curves
  - Conservative and comprehensive extraction of negative as well as positive constraints
  - Transitive dissemination of constraints
  - Use of events to refine node location
- Sextant is practical
  - Deals well with violations of simplistic assumptions
  - Implemented on MICA-2 motes, PDAs and laptops

http://www.cs.cornell.edu/People/egs/sextant/

# Related Work

## Positive Information

- **GPS-Free** '01: Capkun, Hamdi and Hubaux
- **APS** '01: Niculescu and Nath
- **Convex Position Estimation** '01: Doherty, Pister and Ghaoui
- **Robust Positioning** '02: Savarese, Rabay and Langendoen
- **N-hop Multilateration** '02: Savvides, Park and Srivastava
- **APS-AoA** '03: Niculescu and Nath
- **Mere Connectivity Localization** '03: Shang, Ruml, Zhang and Fromherz
- **Connectivity-Based Positioning** '04: Bischoff and Wattenhofer
- **Unit Disk Approximation** '04: Kuhn, Moscibroda and Wattenhofer
- **Virtual Coordinates** '04: Moscibroda, O'Dell and Wattenhofer

# Related Work

## Single-Hop

- **Active Badge** '92: Want, Hopper, Falcão and Gibbons
- **GPS-Less** '00: Bulusu, Heidemann and Estrin
- **RADAR** '00: Bahl and Padmanabhan
- **Cricket** '00: Priyantha, Chakraborty and Balakrishnan
- **RF-Based Location Tracking** '04: Lorincz and Welsh
- **VORBA** '04: Niculescu and Nath
- **Localization Using a Moving Target** '04: Galstyan, Krishnamachari, Lerman and Pattem

# Related Work

## Event Localization

- **Fine-grained Localization** '01: Savvides, Han and Srivastava
- **Collaborative Processing** '03: Zhao, Liu, Guibas and Reich
- **Acoustic Ranging** '04: Sallai, Balogh, Maroti and Ledeczi
- **Countersniper** '04: Simon, Maroti, Ledeczi et al.
- **Entity Tracking** '02: Brooks, Griffin and Friedlander
- **Energy-Efficient Surveillance** '04: He, Krishnamurthy, Stankovic et al.