Tracking Indoors

Location of what?

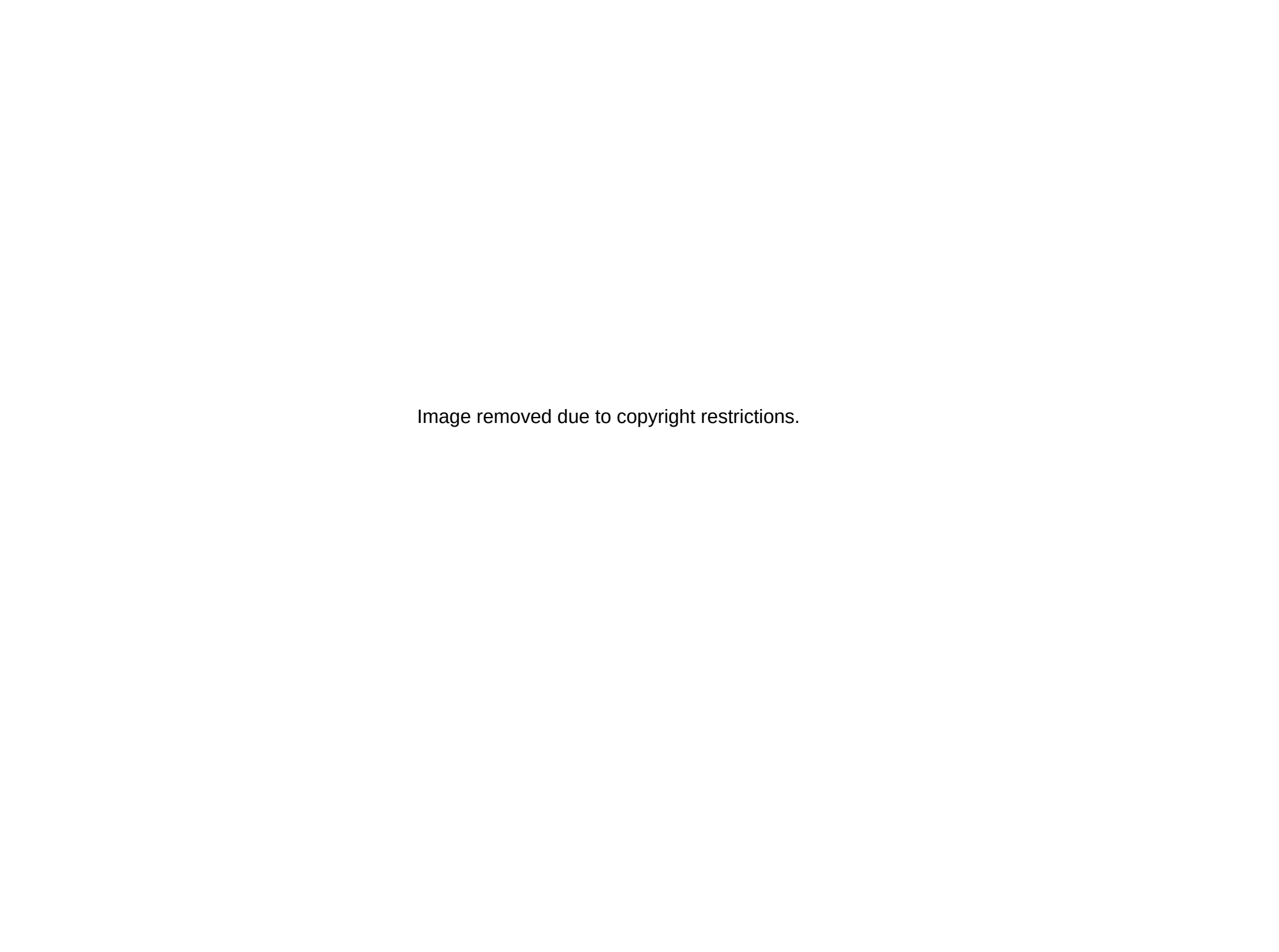
- Objects
  - Static, Moveable, or Mobile
    - Frequency of movement: door, desk, laptop
  - Dumb or Networked
- People
  - Waldo asks “Where am i?”
  - System asks “where’s Waldo?”
- Services
  - applications, resources, sensors, actuators
  - where is a device, web site, app

Tracking technology

- Some examples:
  - 802.11; Bluetooth (Intel, HP, ..), RFID
  - ParcTab (Xerox)
  - Active Badge (Cambridge ATT)
  - BATs (Cambridge ATT)
  - Crickets (MIT)
- Cameras

Tangential Note: Larry's conjecture

- Any sensing service in pervasive computing only needs:
  - some cameras
  - lots of computing power
  - some clever algorithms
- Any sensing service in pervasive computing
  - can be done cheaper with application-specific hardware!
  - E.g: Location tracking & recognition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Cambridge ATT’s BAT

Cambridge ATT's BAT

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Cambridge ATT's BAT

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BAT Details

- Ultrasound transmitters
  - 5 cm x 3 cm x 3 cm; 35 grams
  - unique id (48 bit)
  - temp id (10 bit) -- reduces power
  - button (just one)
  - rf transceiver
- Receivers in ceiling
- Base station
  - periodically queries, then bats respond
  - query time, recv time, room temp
    - 330 m/s + .6*temp; >2 receivers ==> location

More on BATs

- Deployment
  - 50 staff members, 200 BATS, 750 Receivers, 3 Radio cells, 10,000 sq ft office space
- 20 ms per bat enables 50 BATs / sec
- Smart scheduling reduces BAT's power
  - while at rest, reduce frequency of query
  - detect activity at PC to deduce "rest"
- Convert BAT location to object location
- Centralized Datebase
  - less latency than distributed query
  - better filtering and error detection

Feedback of Location-service

- Human-centric view of location information
- Cuteness reduces concern over privacy

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Programming Model?

- Analogous to window-system. BAT enters workstation space, causes an event call-back

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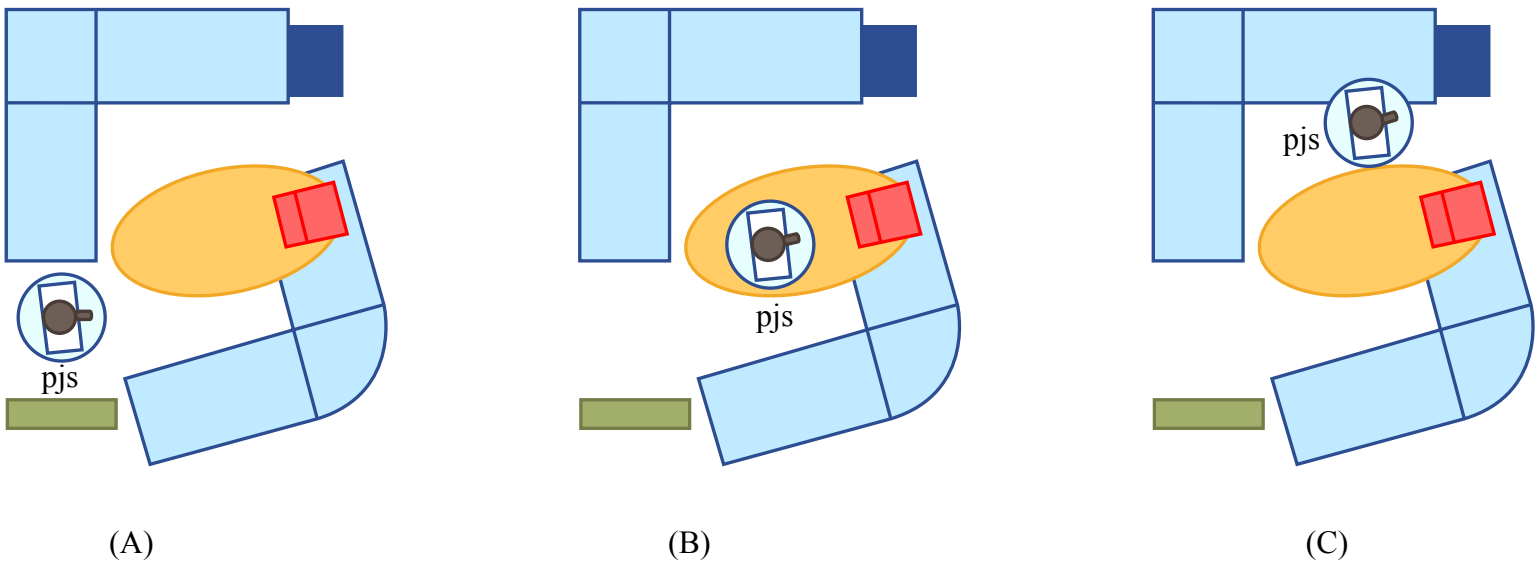
Application: Follow-me Desktop



Spatial monitoring application that moves users' desktops around with them. The application registers with the Spatial Monitor:
(A) As the user (pjs) approaches the display
(B) Or moves away from it
(C) The spatial monitor sends a positive or negative containment event to the application that transfers or removes the desktop to or from the screen.

Figure by MIT OCW.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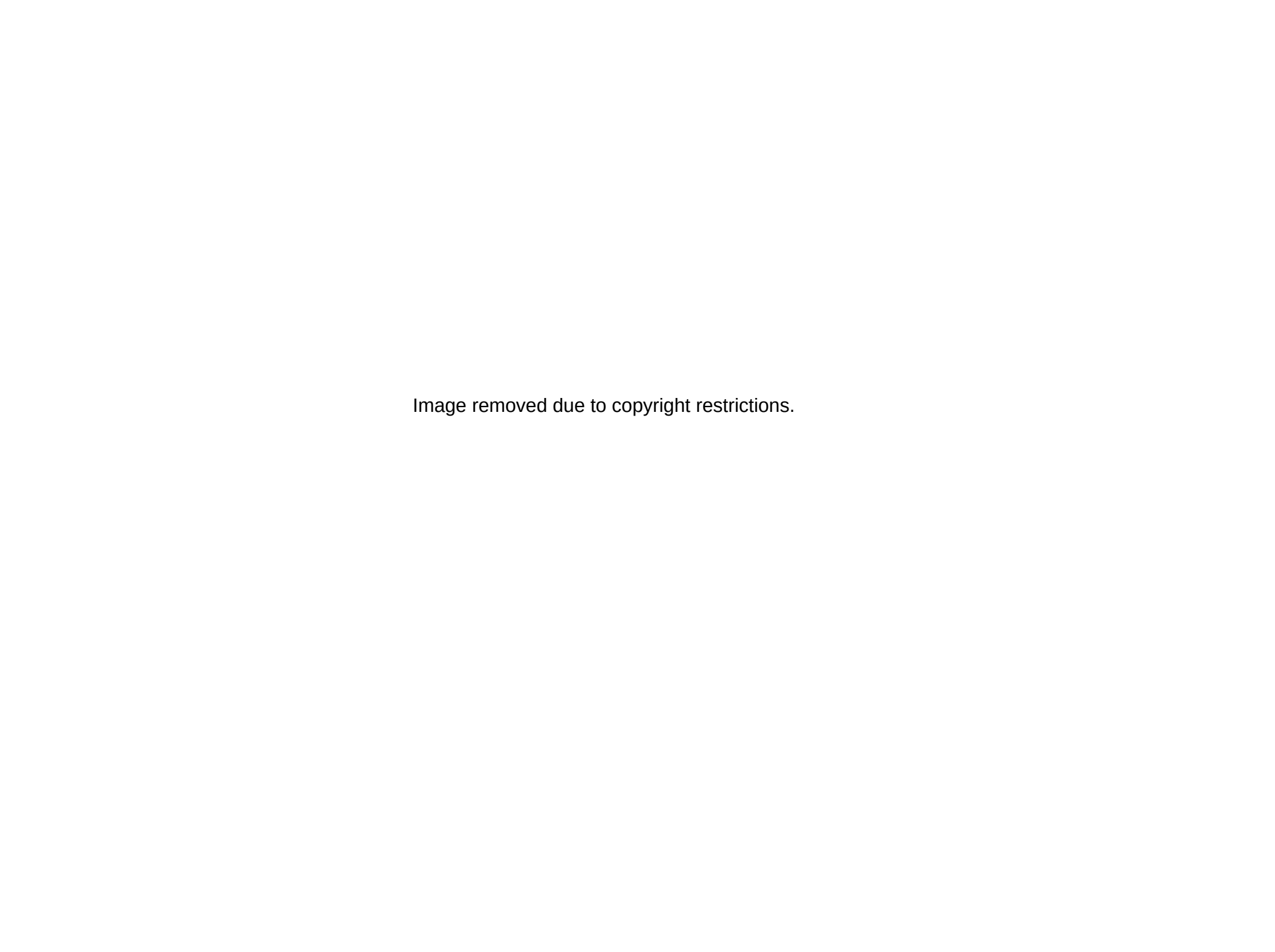
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How well does it work?

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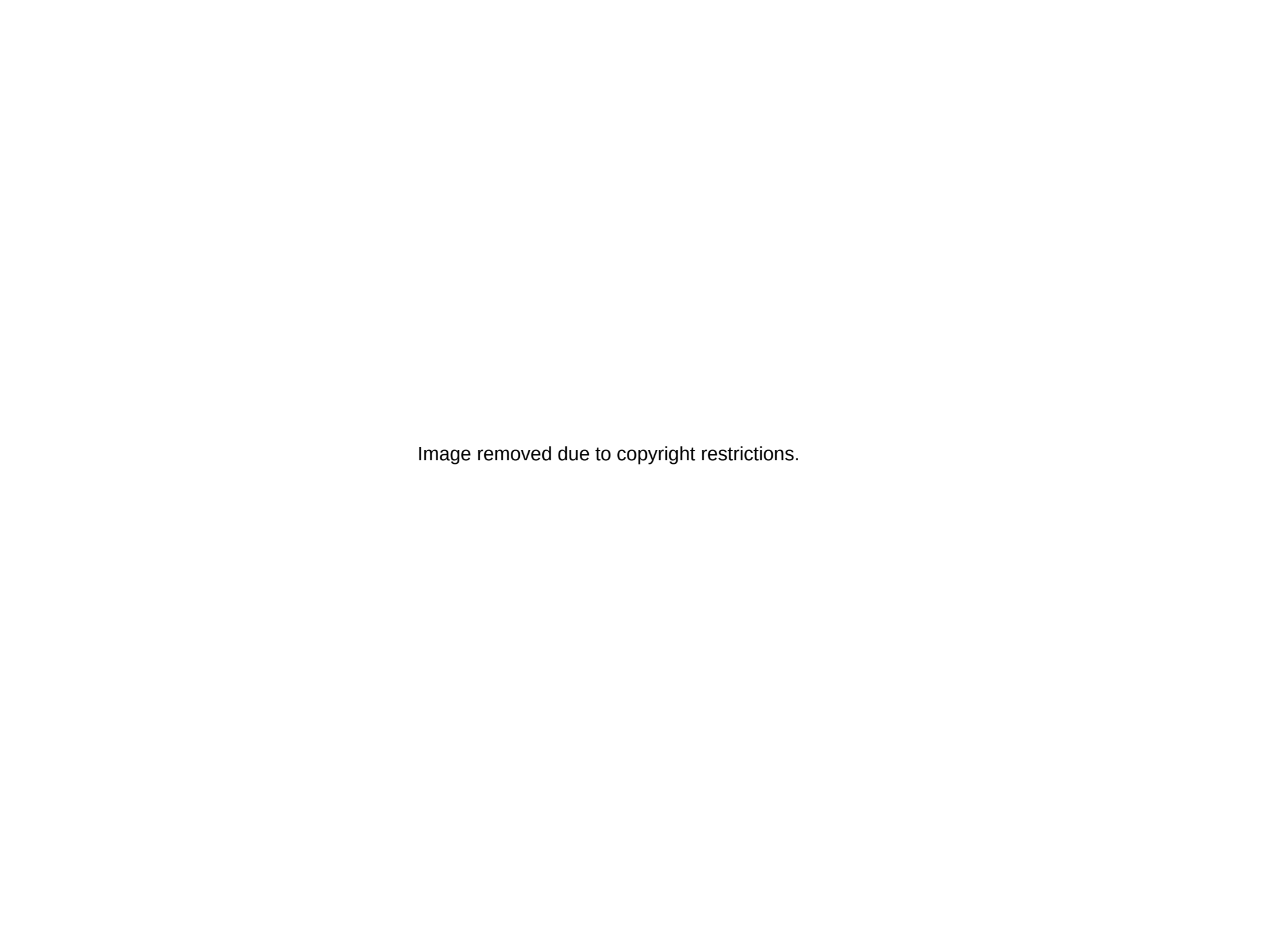
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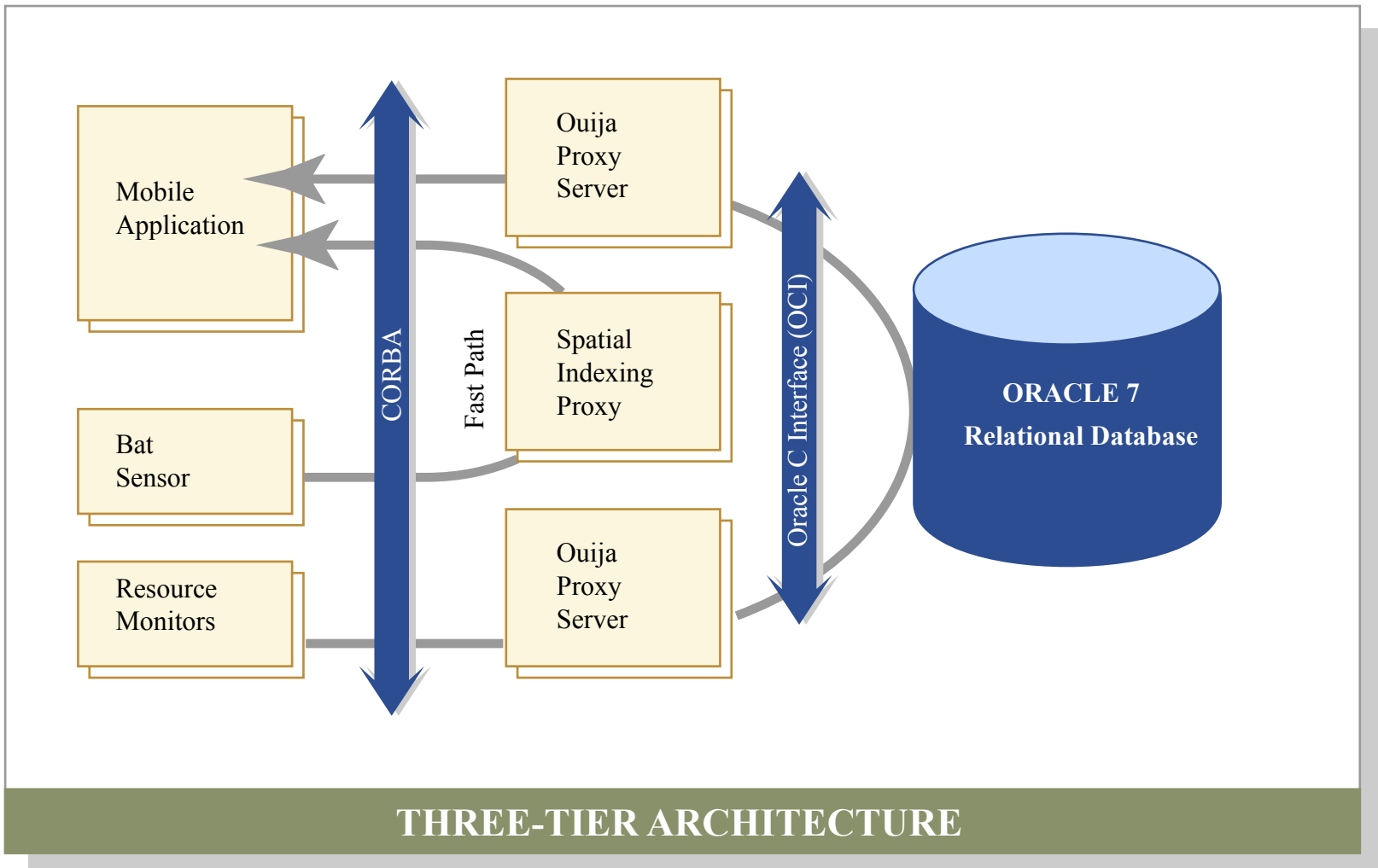


Figure by MIT OCW.

Better Trackers

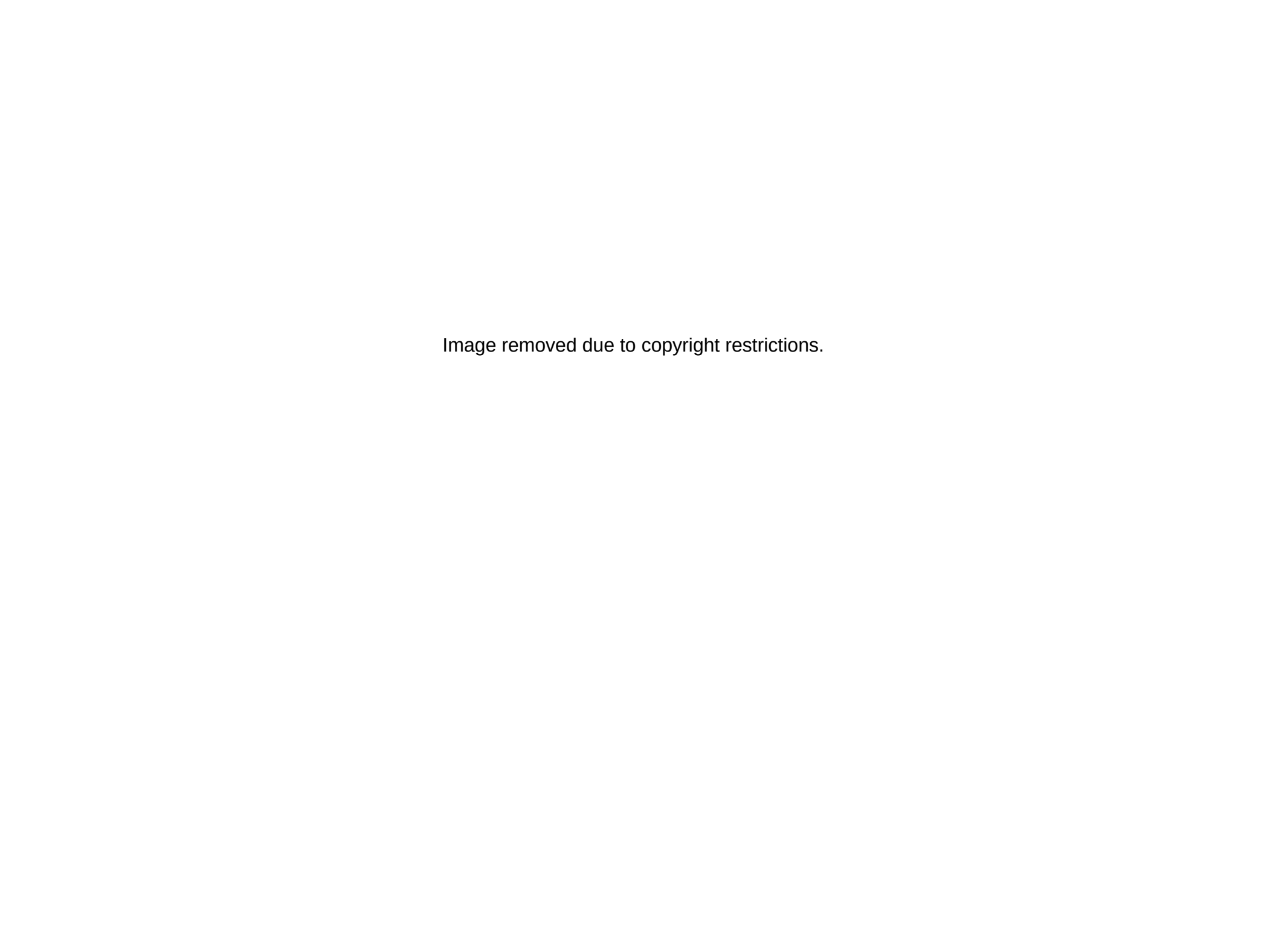
- Bayesian filtering on sensory data
- Predict where person will be in future.
  - position and speed over near past
  - behavior (avg speed) over long term
- Uses
  - Filter bad sensory data
  - Likely place to find someone
  - Predict which sensors to monitor

A few details of Bayesian Filtering

Bayes filters estimate posterior distribution over the state x_t of a dynamical system conditioned on all sensor information collected so far:

To compute the likelihood of an observation z given a position x on the graph, we have to integrate over all 3d positions projected onto x:

See “Voronoi tracking …” Liao, et al.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Universal Location Framework

- Stack: Sensor, Measure, Fusion, Application
- Location API (preliminary)
  - What: timestamp, position, uncertainty
  - When: Automatic (push), Manual (pulll), Periodic
- 802.11 base station location
  - Calibrated database of signal characteristics
  - 3 to 30 meter accuracy

Division of Labor

- Determining the location of object
- Associating name with location
  - Object (or person) has name
  - Object has a location
    - physical or virtual (instantiation of program on some machine)
- Need scalable solution to connect them
  - RFIDs demand scalability