SATware: Middleware for Sentient Spaces

WMSC 2007

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Sensing layer

Ad-hoc Application

Uninterpreted streams of sensor event observations

QoS
Privacy

Traditional sensor network
SATware: Semantic Layer

- **Sensing layer**
  - Uninterpreted streams of sensor event observations
  - Interpreted streams of entity-related events

- **Semantic layer:**
  - Entities and activities

- **Application**
  - Input from user
  - Output to user

- **Domain model**
- **Situation model**

- **QoS**
- **Privacy**

**Uninterpreted Streams of Sensor Event Observations**

**Interpreted Streams of Entity-Related Events**

**Domain Model**

**Situation Model**
SATware: Challenges

In emergency response, being able to specify quality of the service and having the system guarantee it is crucial.

Privacy of users (both direct and indirect users) has to be protected.

In emergency response failures happen.

Different levels of abstraction from user's high abstraction level to sensors' level. Users care about entities and events.

Different kinds of sensors: different resources, mobility capabilities, data streams produced (scalar, video), phenomena being sensed.

Lots of sensors. Some sensors produce streams with very high sample rates and sample sizes (e.g., video).

Sensors and services need to be added, removed and discovered.

In emergency response, failures happen.

Different levels of abstraction from user's high abstraction level to sensors' level. Users care about entities and events.

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In emergency response failures happen.

Different kinds of sensors: different resources, mobility capabilities, data streams produced (scalar, video), phenomena being sensed.

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Sensors and services need to be added, removed and discovered.
Queries written at the **entity level**

- E.g., *Identify who left the coffee pot burning?*
- E.g., *Notify when someone leaves a mess in the shared kitchen.*
- E.g., *Notify when Sharad is in the shared area and his status is “Not Busy”.*
- E.g., *Notify when Iosif and Sharad are both in the shared area.*

*Queries are translated into Operators*
A stream is an infinite discrete flow of packets:

stream = list(packet)

packet = <t, c>

t: time stamp

c: content

C ∈ domain(DT)
DT := int | float | char | byte | void | bool | event
DT := list(DT) | tuple(DT)
Event := <event_id, confidence, DT>

<14:01:12.50 Jan 1st 2007, <LocationChange, 0.65, void>>
Stream processing model
-Processing model-

Processing based on operators

\[
OP = \{ f_{DTx...xDT} \mid f_{DTx...xDT} : \text{stream}_x...\text{stream}_x \rightarrow \text{stream} \}
\]

- Code reuse
- Sharing operator instances
- Simplify design
- Load distribution

Virtual sensors

WhoBurnedCoffee_{x,y} = \text{O10}(\text{CoffeeBurn}_x, \text{PersonID}_y)

Image processing-based event detection

< t_i , <Jpeg image> >

Time synchronizer

\[
\begin{align*}
&< t_i , \langle \text{PersonID}, c_i \rangle > \\
\mathcal{O}_i &
\end{align*}
\]

\[
\begin{align*}
&< t_i , <\text{Door Status}, c_m> > \\
&< t_i , <\text{Door Status}, c_m>> \\
\mathcal{O}_i &
\end{align*}
\]

Event-based event detection

\[
\begin{align*}
&< t_i , <\text{PersonID}, c_i>> \\
\mathcal{O}_i &
\end{align*}
\]

\[
\begin{align*}
&< t_i , <\text{ID}_\text{Enter}_y, c_k>> \\
\mathcal{O}_i &
\end{align*}
\]

Source

\[
\begin{align*}
&< t_i , \langle \text{Jpeg image} \rangle > \\
\mathcal{O}_i &
\end{align*}
\]

Output

\[
\begin{align*}
&< t_i , \langle \text{PersonID}, c_i \rangle > \\
\mathcal{O}_i &
\end{align*}
\]

User
UCI has been instrumented with a large set of sensors throughout all campus.

The instrumentation would allow conducting a quick assessment of the status of buildings from any device that has access to Internet by accessing an online Remote Windshield Assessment application.

The system would allow any user (for example, UCIPD) to register for events.
Sample query

Query: Notify when there is a change of distribution of people in a building

Event detection 1:
Estimation of number of people in and out a certain door.

Event detection 2:
Estimation of number of people in a room.

Source agent:
Gets JPEG frames from a network camera.

Source agent:
User interface.
SATware architecture

- SATRuntime
- SATDeployer
- SATLite
- SATQL

Sensor infrastructure

Heterogeneous sensors

Application

High-level query language

Deployment (topology) description

Deployment optimization

Distributed Reflexive Mobile-agent based runtime

User

<Query results>

<Query>_{SATQL}

<Query>_{SATLite}
Runtimes are connected instead of the agents.
Agents are programmed in a topology-agnostic manner.
SATRuntime provides mobility support and message-passing.

SATRepository contains
- repository of operators and state of SATware (sensors, runtime nodes, network topology, and current operator deployment).
Sample query
// operators
O1 = CreateOperator(ReadCam, camera_url);
O3 = CreateOperator(DetectBurner);

// data flows
Image = O1();
BurnerStatus = O3(Image);
BurnerOn = O6(BurnerStatus);
O11(PersonId);
Given

- Sequence of selection predicates
  - \( \lambda_1, \lambda_2, \ldots, \lambda_n \)
- With Per-tuple cost:
  - \( c_1, c_2, \ldots, c_n \)
- And **MAYBE** selectivity: #Maybe / #All
  - \( m_1, m_2, \ldots, m_n \)
- Such that:
  - \( c_1 < c_2 < \ldots < c_n \)
  - \( m_1 > m_2 > \ldots > m_n \)

Determine the least cost execution plan for \( \lambda_n \)

\[ \lambda_k(t) = \begin{cases} 
  Yes & \text{if} \ k \text{ is true} \\
  No & \text{if} \ k \text{ is false} \\
  Maybe & \text{if} \ k \text{ is uncertain} 
\end{cases} \]
Solutions

Optimal Generalized Plan

Individualized Handling

Tuple Grouping

Translating a query plan into a deployment plan
- Mapping query plan nodes into processing nodes

Minimizing query processing cost
- Network cost
- Computing cost
- Query evaluation time

Optimizations
- Operator reuse
- Load balancing
Privacy is protected unless the user violates a specific rule.

Abnormal event detection

Aggregated behavior of human beings:
\[ N(t) = N_0(t) + N_E(t) \leftrightarrow \text{Markov Modulated Poisson} \]

Normal behavior: periodicity
\[ N_0(t) \sim P(N; \lambda(t)) \leftrightarrow \text{Time-Varying Poisson} \]
\[ \lambda(t) = \lambda_0 * \delta_{d(t)} * \eta_{d(t),h(t)} \]
\[ 1 \leq d(t) \leq 7 \text{ and } 1 \leq h(t) \leq 48/288/… \]

Abnormal behavior: rare and short
\[ z(t) = 0 \]
\[ N_E(t) \sim P(N; \gamma(t)) \quad z(t) = 1 \]
\[ z(t) \sim \text{Markov Process} \]

Unsupervised learning of model parameters via statistical methods (MCMC)

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Responsphere:

1/3 UCI campus:
2 Indoor buildings + Outdoors
+200 sensors +10 types
Summary

Sentient systems

Challenges

Layered architecture

Privacy applications
Thank you

http://satware.ics.uci.edu
Extra slides
Project RESCUE  
June 20, 2007

http://www.itr-rescue.org

Funded through National Science Foundation Funding:

ITR award

NSF Research Infrastructure award
The mission of RESCUE is to enhance the ability of emergency response organizations and the public to mitigate crises, save lives, and prevent secondary and indirect human and economic loss by radically transforming ways in which these organizations gather, process, manage, use and disseminate information during man-made and natural catastrophes.
Hypothesis: **Right Information** to the **Right Person** at the **Right Time** can result in dramatically better response:

- Lives & property saved
- Damage prevented
- Cascades avoided

- First responders
- Consequence planners
- Public

- Incidences
- Resources
- Victims
- Needs
Research Team

- Privacy
- Security
- Trust

- Natural Hazards Center
- Social Science

- Data Management
- Security and Trust

- Disaster Analysis
- Earthquake Engineering
- GIS

- Civil Engineering
- Data Analysis & Mining
- Data Management
- Middleware & Distributed Systems

- Civil Engineering
- Transportation Engineering

- Computer Vision
- Networking
- Multimodal Speech

- Transportation Modeling
- Urban Planning

- Privacy
- Social Science
- Transportation Science

- Wireless
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<th>Industrial Partners</th>
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<tr>
<td><strong>5G Wireless</strong></td>
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<tr>
<td>Broad-ranged IEEE 802.11 networking</td>
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<td><strong>Apani Networks</strong></td>
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<td>Data security at layer 2</td>
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<td><strong>Boeing</strong></td>
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<td>Community Advisory Board Member</td>
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<td>Software partnership</td>
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<td>Camera Equipment and SDK</td>
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<td><strong>IBM</strong></td>
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<td>Smart Surveillance Software (S3) and 22 e330 xSeries servers</td>
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<td><strong>Microsoft</strong></td>
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• **Social Science**
  - context and understanding of crisis domain

• **Information Technology**
  - infrastructure & tools to enhance flow of information & situational awareness

• **Engineering**
  - platform for realization, real-world physical constraints that help test, and validate
Project Structure

RESOLUTE Thrust Areas

INFORMATION COLLECTION
INFORMATION ANALYSIS
INFORMATION SHARING
INFORMATION DISSEMINATION

Policy Engine
Real-time Alert System
Robust Networking Solution
Risk Communication System

Smart Reconnaissance System
Enterprise Service Bus
Integrated Information Dashboard
Internet-based Loss Estimation System

CHAMPAIGN
METASIM
CAMAS
GLQ

FUTURE TESTBEDS

Integrative Artifacts

Testbeds

RESOLUTE Research Projects

Policy-driven Information Sharing
Privacy

Situation Awareness
Robust Networking
Customized Dissemination