Cyber-Physical Event Processing

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CSE 520S
References

Core material of this lecture:


Other references:

- TAO http://www.cs.wustl.edu/~schmidt/TAO.html
Industrial Internet of Things (IIoT)

- IIoT = Cyber-physical systems + Cloud
- Cyber-physical event processing as a service
Application example

- Monitoring a farm of 100 acres (i.e., 75+ football fields)

Application example

- Monitoring a nation-wide smart electric grid

Application example

- Predictive maintenance
  - The prediction of and response to component failures
  - E.g., maintaining wind turbines in a wind farm
Cyber-physical event processing as a service

- Example: sensor fusion
  - Reducing data noises
  - Creating frequency domain representation
  - Concatenating results for a broaden spectrum assessment

![Diagram of sensor fusion process]

EKF: Extended Kalman Filter  FFT: Fast Fourier Transform  CAT: Concatenation
Research challenges

- Enforcing QoS policies
  - e.g., latency differentiation
- Computationally intensive
  - e.g., sensor fusion
  - High input rate
- Event temporal validity
  - Freshness of sensing data

Diagram:

```
EKF_1 > FFT_1 > CAT_1 > FFT_2 > EKF_2
```

from sensors

to applications
Related work

- **Real-time event services**
  - Real-time CORBA
    - Industry standard
    - Predictable and interoperable data exchanges between systems
  - TAO
    - CORBA-compliant C++ open-source implementation
    - Widely used in industry in the past two decades
  - Data Distribution Service (DDS)
    - Industry standard
    - Data-centric paradigm; publish-subscribe pattern

- **Complex event processing (CEP)**
  - T-REX
    - Efficient implementation for a rich set of event processing rules
  - GraphCEP
    - Social network analysis (e.g., Facebook post ranking)
Related work

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  - CORBA
    - Real-time CORBA
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Related work

- **Real-time event services**
  - Do not perform complex event processing ...

- **Complex event processing (CEP)**
  - Do not differentiate application QoS ...
  - Do not support real-time at the millisecond scale ...
Cyber-Physical Event Processing (CPEP)

Real-time CPEP middleware

✓ Processing prioritization
✓ Processing sharing
✓ Enforcing temporal validity

System configuration

- Constructing the graph of event streams from a file
  - Operator arrangement
  - Consumer priority levels

- Prioritizing operators
  - Priority propagation from consumers
Processing prioritization

Schedule the threads using a fixed-priority preemptive scheduling policy
Processing sharing

Save the time for lower-priority processing!

Movers don’t interfere with higher-priority processing!
Enforcing temporal validity

Absolute validity intervals:

The interval for $S_2$

The interval for $S_1$

The interval for $S_3$

An event for $C_2$ is temporally valid only before timepoint $t_4$
Enforcing temporal validity

Absolute validity intervals:

The interval for $S_2$

The interval for $S_1$

The interval for $S_3$

An event for $C_2$ is temporally valid only before timepoint $t_4$

CPEP sheds invalid events for both correctness and efficiency
CPEP implementation

- Implemented based on RT-CORBA event service
  - TAO real-time event channel (version 2.3.0)

- Efficient memory management
  - Zero-copy of same event for downstream operators

- Replacing older events by new instances
  - Data freshness for physical states
Empirical evaluation

- **Experimentation setup**
  - Machine 1
    - Event suppliers
  - Machine 2 ("The middle box")
    - CPEP
  - Machine 3
    - Event consumers

- **Evaluating performance on**
  - Prioritization
  - Sharing
  - Shedding

- **Workload:** sensor fusion emulation, etc.
  - Consumers of multiple priority levels
  - Suppliers of multiple sending rates
  - Sharing of operators
Graphs of event streams #1

- Consumers of multiple priority levels
- Suppliers of multiple sending rates
Graphs of event streams #2

- **Sharing of operators**

- **Non-sharing**

10/9/17
Protect the latency of high-priority events against contention
CPEP sharing: results

Sharing reduced the latency of lower-priority processing

Without sharing, no low-priority events were produced!
CPEP shedding: results

Valid throughput = temporally valid events / second

Shedding can improve temporally valid throughput

Graph showing the comparison of high-priority valid throughput between with and without shedding as the number of event streams increases.
CPEP shedding: results

Valid throughput = temporally valid events / second

Shedding can improve temporally valid throughput
Summary

- Cyber-physical event processing is vital for Industrial IoT
- Three main contributions of the CPEP middleware
  - Processing prioritization
  - Processing sharing
  - Enforcing temporal validity