Stream Reasoning and Linked Data: A Clash of Cultures

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2nd RDF Stream Processing Workshop
ESWC 2017
Outline

• Act I: Status quo and life-changing event
• Act II: We have achieved some alignment but still no dice
• Act III: An attempt at convergence
ACT I

Status quo and life-changing event
„Nothing Endures But Change“

• Current and future scenarios around the Internet of Things and the Web of Things require processing of (near) real-time data

• Frillions of sensors in the near future

• We need systems for processing live data (e.g., read a temperature sensor or a website clickstream)

• The systems should also support actuators (e.g., set a heating/cooling system or send an email message)
Requirements

• Process data in near-realtime (sub-second) for live query, control, virtual reality/augmented reality
• Handle dynamics and behaviour (of both systems and humans)
• Connect different subsystems (sensors, actuators; tracking, simulation, rendering...)
• Integration of data sources and interoperation between systems

• Web-scale: simple, elegant, robust, decentralised, many participants
Which Data Model? Which Data Format?

- CSV
- JSON
- Protocol Buffers
- .NET
- Avro
- RDF
- Java
- XML
- RMI
- CAP’N Proto
Which Network Protocol?

- ROS
- UPnP
- MQTT.org
- DDS
- XMPP
- WAMP
- http://
- AMQP
- SOAP-ENV: Envelope
  - SOAP-ENV: Header
  - SOAP-ENV: Body
- CoAP
- Stomp
Which IoT Platform?

- Microsoft Azure IoT Hub
- Google Cloud Platform
- Cloud Connections
- ORACLE
- Cisco
- Bosch IoT Suite as Platform as a Service
- Predix™
- SAP
- IBM Watson IoT
- salesforce
- AWS IoT
• Semantic: Why not agree on RDF as data model?
• Web: Why not agree on HTTP as network protocol?
• Web: Why not agree on a decentralised architecture?
Web Architecture (1990)

https://www.w3.org/People/Berners-Lee/1996/ppf.html
Linked Data Architecture (2009)

https://www.w3.org/2009/Talks/0204-ted-tbl/#(7)
Web of Things Architecture (2015)

The Web as the Solution

"Things" as virtual objects acting as proxies for physical and abstract entities
metadata, events, properties, actions
(over a variety of protocols including HTTP)

https://www.w3.org/2015/05/wot-framework.pdf
ACT II

We have achieved some alignment but still no dice
Linked Data Interface

- Sensor has URI (e.g., http://localhost/sensor/temp)
- GET on http://localhost/sensor/temp returns current reading
SPARQL Query Current Temperature

SELECT ?temp
FROM <http://localhost/sensor/temp>
WHERE {
}
Read-Write Linked Data Interface

• Actuator has URI (e.g., http://localhost/actuator/gpio1)
• PUT on http://localhost/actuator/gpio1 switches an electric consumer on or off (with the right RDF message body)
Simple Reflex Agents

Or other cognitive architectures: SOAR, ACT-R…

Simple Thermostat Reflex Agent

• Loop forever:
  • GET http://localhost/sensor/temp
  • Query ?x rdf:value ?temp .
  • If ?temp > 25 °C:
    • PUT http://localhost/actuator/heating
    • With some RDF to set heating to OFF
  • If ?temp < 20 °C:
    • PUT http://localhost/actuator/heating
    • With some RDF to set heating to ON
  • Wait 1 minute

• The Reflex Agent is acting as user agent
But I Want Streaming!

Uniform Network Interface

• Components A and B, data flows from A (source/producer) to B (sink, consumer)

• REST assumes request/response communication pattern between components with client connector and server connector
  
  • Clients emit requests, receive response
  
  • Servers answer to incoming requests with a response
Network Interface: Push vs. Pull

**Push**
- A is client, B is server
- A emits PUT request
- At A: B.put(value)
- Loop at A

**Pull**
- A is server, B is client
- B emits GET request
- At B: value = A.get()
- Loop at B
Bi-directional Communication in HTTP

• Stream processor acts as server (which processes incoming HTTP requests)
• For publish/subscribe, each component is both client and server (a transducer)
Actor Model (1973)

“Actors communicate with each other by sending asynchronous messages. Those messages are stored in other actors' mailboxes until they're processed.”

http://www.brianstorti.com/the-actor-model/

Carl Hewitt; Peter Bishop; Richard Steiger (1973). "A Universal Modular Actor Formalism for Artificial Intelligence". IJCAI.
Message Bus (for Stream Processing)

Message bus systems centralise the actors' mailboxes.

Examples are:

- ROS
- Kafka
- ...

http://www.enterpriseintegrationpatterns.com/img/MessageBusSolution.gif
Protocol/Architecture

Linked Data
• Distinction between client (user agent) and server
• User agents invoke requests, servers answer with responses
• Server is persistent
• No central message broker needed

Stream Processing
• No clear distinction between client and server
• All components can send messages and receive messages
• All components are persistent
• Some variants rely on central message broker
Time


In comics, as in film, television and "real life," it is always NOW.

This panel and this panel alone represents the present.

Any panel before this--that last one, for instance--represents the past.
Aspect: State vs. Event

- Event: Leonard Cohen is born on September 21, 1934
  [] a :Event ; :type :birth ; :date "1934-09-21" .

- State: Leonard Cohen
  :lc :birthDate "1934-09-21" .

  [] a :Event ; :type :death ; :date "2016-11-07" .

- State: Leonard Cohen
  :lc :birthDate "1934-09-21" .
  :lc :deathDate "2016-11-07" .
Aspect of Data Representation

**Linked Data**
- Messages represent resource state
- Getting the combined current state of resources involves GETs on URIs

**Stream Processing**
- Messages represent events
- Some messages represent state as well
- Getting the combined current state of resources requires integration of events
ACT III

An attempt at convergence
Selected Projects Using Reflex Agent Model

- **ARVIDA: Applied Reference Architecture for Virtual Services and Applications**
  - Break up monolithic industrial applications into distributed applications
  - Components based on RESTful interfaces
  - RDF, RDFS and OWL for knowledge representation (vocab.arvida.de)

- **i-VISION: Immersive Semantics-based Virtual Environments for the Design and Validation of Human-centred Aircraft Cockpits**
  - Human-Cockpit Operations Analysis
  - Semantic Virtual Cockpit
  - Virtual Cockpit Design Environment
Demo Setup
Linked Data Notifications

W3C Recommendation 2 May 2017

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Abstract

Linked Data Notifications is a protocol that describes how servers (receivers) can have messages pushed to them by applications (senders), as well as how other applications (consumers) may retrieve those messages. Any resource can advertise a receiving endpoint (Inbox) for the messages. Messages are expressed in RDF, and can contain any data.
Open Questions Stream Processing

• When to trigger query evaluation?
  • Every triple? (event-triggered)
  • Every incoming request? (event-triggered)
  • Every time slice? (time-triggered)

• When to trigger actions?

• How to integrate event and state messages?

• How to perform reasoning?
  • Over each message individually?
  • Over entire state at each time step?
Conclusion

• In the Semantic Web community, building on HTTP and RDF seems reasonable (to me)
• Linked Data and Stream Reasoning systems have different characteristics, leading to differences in user agent/server roles
• In dynamic environments, the modelling of aspect warrants some attention, especially in conjunction with request/response and reasoning
• Reflex agents provide a simple model for operating on resource state
• Linked Data notifications could provide a model for the handling of events in stream processing and stream reasoning systems
Linked Data Processing vs. Stream Processing

• What is the current temperature?  

\[
\text{SELECT} \ ?\text{temp} \\
\text{FROM} \ <\text{http://localhost/sensor/temp}> \\
\text{WHERE} \ \{ \\
\quad ?x \ \text{rdf:value} \ ?\text{temp} . \\
\} \\
\]

• Notify me when somebody accesses the web page foo.html!

\[
\text{tail} \ -f \ \text{access.log} \\
\quad | \ \text{grep} \ -e \ \text{foo.html} \\
\quad | \ \text{while} \ \text{read} \ -r \ \text{line}; \ \text{do} \\
\quad \quad \text{mail} \ -s \ "hit" \ \text{harth@kit.edu}; \\
\quad \text{done}
\]
UML State Diagrams vs. UML Activity Diagrams

Boxes represent states
Arrows represent events (transitions)

Boxes represent activities
Arrows represent states
Further Reading


