Agents and Semantics for Human Decision-Making

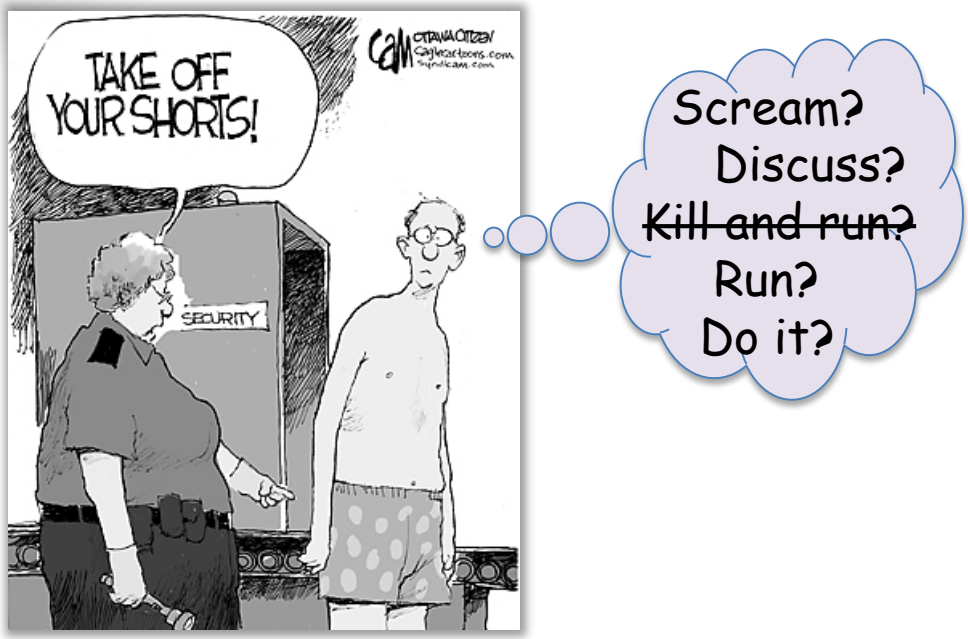
PD Dr. Matthias Klusch

Agenda

- Introduction
  - Decision Making and Support Systems
  - Agents and Semantic Technologies
- Agent-Based Semantic Decision Support
  - Showcases
  - Challenges

Human Decision-Making

Recently
at the airport
…



Cognitive process of an **individual**, or a **group** which results in a final **choice**, or an opinion of choice **of a course of action** among **alternative** scenarios to accomplish given objective(s) ….

Decision-Making Model

Generic 7-Step Model

(Brown, 2012)

w/ feedback loops between steps

Since the 1950s

- Detailed in more **specific (multi-criteria)** models based on **perspectives of human decision-making**
  - Psychological: Needs, preferences, values
  - Cognitive: Cont. deliberation integrated w/ environment)
  - Normative: Rational (logical, utility-driven) vs. Irrational choice

  e.g. Recognition Primed Decision Model (Klein, 1989)

- **Decision support systems (DSS)**

  Early: Medical diagnosis, financial management, ...

  ➢ Mathematical models, Statistical methods, data mining/OLAP, logical rule-based …

Intelligent Decision Support Systems

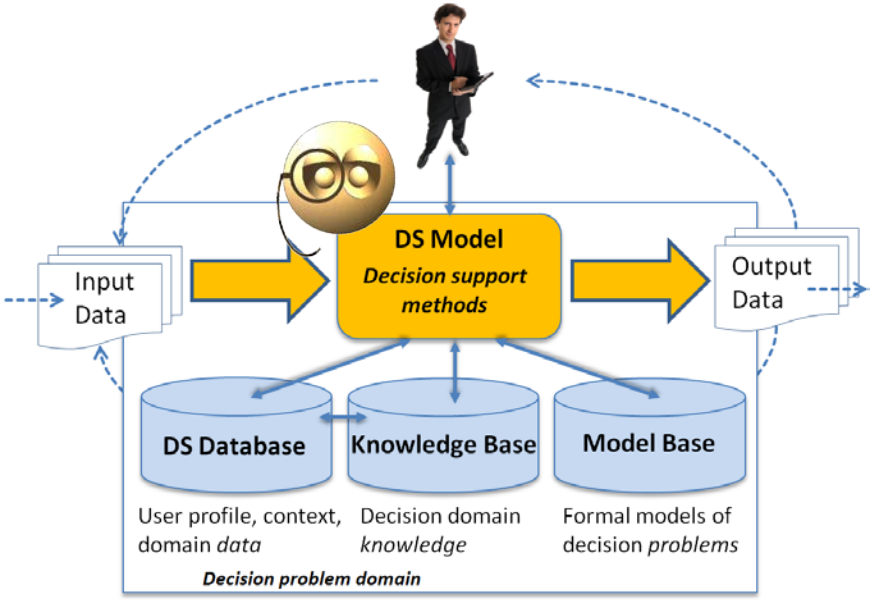
Since late 1970s: Intelligent DSS

(Holsapple & Whinston 1977; Turban & Aronson 1998)

- *Use of **AI techniques** to exhibit „intelligent behavior“ of DSS*
- **Since 1990s**: Use of **agents** in IDSS
- ✓ **autonomous, proactive, reactive**

coordination of data, knowledge, services needed for **personal** and **group decision support**

In distributed environments: **collaborative** (MAS)



Generic IDSS architecture

- GE Phillips-Wren (2008): Intelligent Agents in Decision Support Systems. Encyclopedia of Decision Making and Decision Support Technologies. IGI Global
- dto (2012): AI Tools in Decision Making Support Systems: A Review. *Artificial Intelligence Tools*, 21(2)

Examples

Prominent and mature applications of agent-based decision support include

Manufacturing, Transport & Logistics

✓ MAS for production and fleet management DS via **distributed planning, scheduling**, etc.

E-Business

✓ **Negotiation support** for online market places, auctions

✓ Product **recommendation**

✓ Service **brokerage, matchmaking**

E-Health

✓ MAS for **clinical decision support**

Virtual Worlds

✓ User **avatars** for **group decision support** in virtual team meetings

- K Fischer, JP Müller (2014): Application Impact of Multiagent Systems and Technologies: A Survey. In: AOSE. Springer
- GE Phillips-Wren, LC Jain (2005). Intelligent Decision Support Systems in Agent-Mediated Environments. In: Frontiers in Artificial Intelligence and Applications Series, 115, IOS.

To better cope with problems of

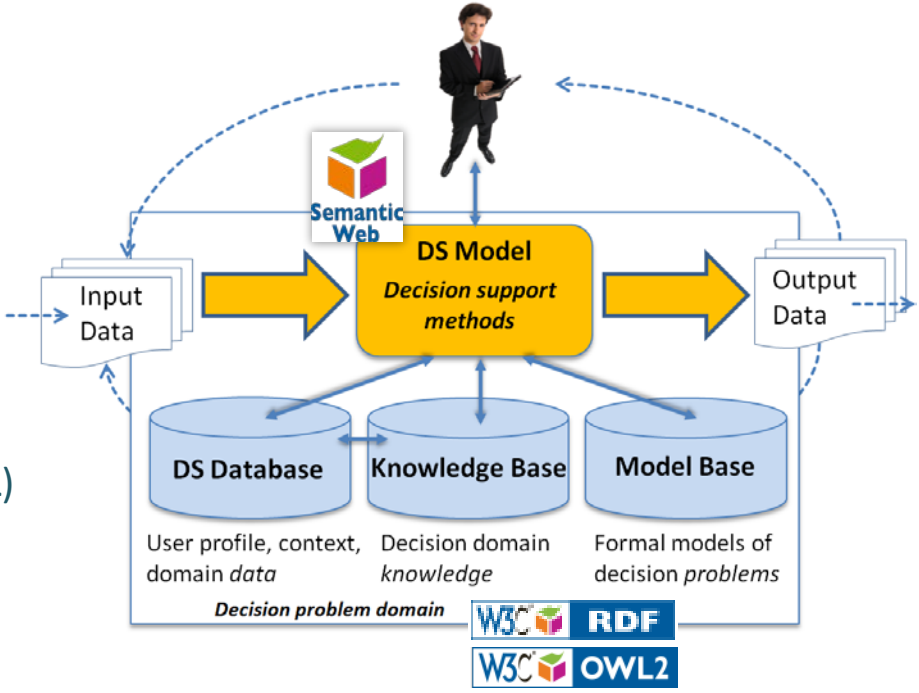
semantic interoperation and reuse

of decision support data, services and knowledge …

Decision Support and Semantic Web

Since 2001: Intelligent DSS also use **semantic Web technologies**

- ✓ **Modelling** of decision domain **semantics** with W3C **standardized** and **formal ontology** and **rule languages** (OWL2, RDF/S, OWL-S, SA-WSDL, RuleML, SWRL)
- ✓ Supported with methods for ontology selection, evaluation, and **alignment**



Examples

Prominent and **standard models** of **semantic decision domains** include:

Domain ontologies (OWL)

- Negotiation [W3C]
- Medical [SNOMED, NIST]
- Sensor Networks [W3C SSN]
- Provenance [W3C PROV-O]

etc.

User profile / context ontologies

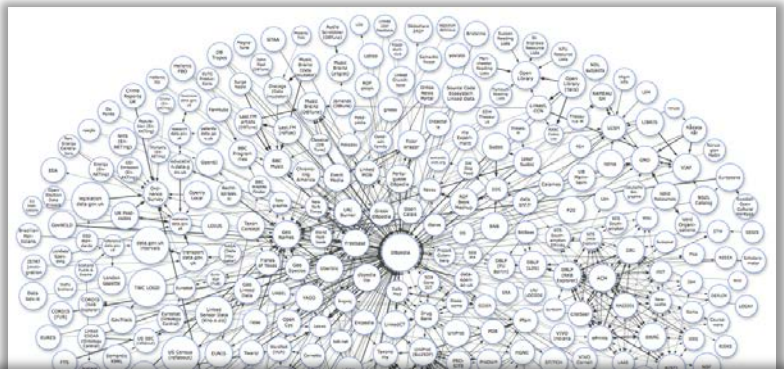
- GUMO (OWL), schema.org, ODP
- AmbiSense

Semantic service collections

- OWLS-TC, SAWSDL-TC, hRESTS-TC

  @semwebcentral.org, >3k services

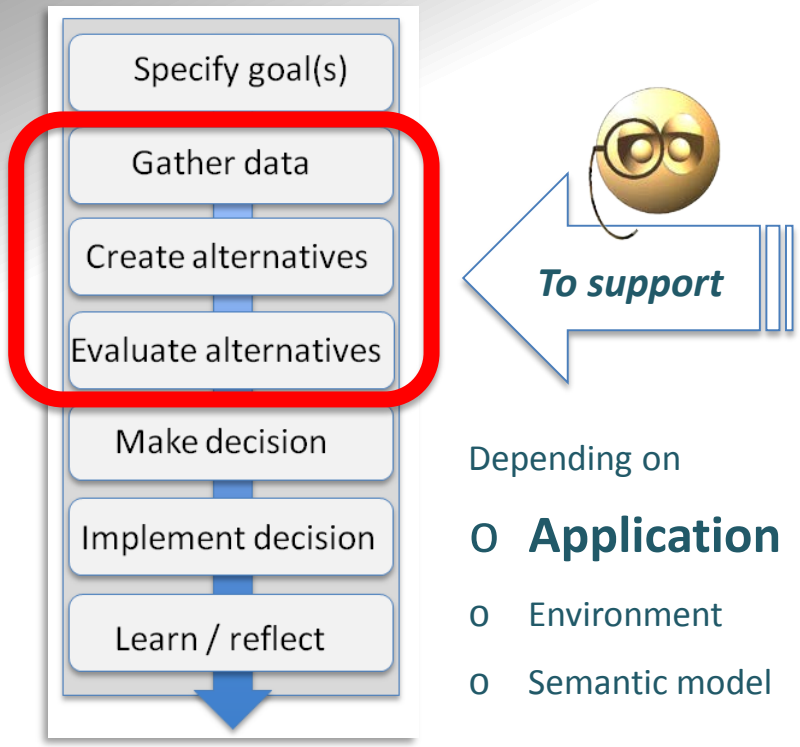
- Various domains: **Linked data sets** (RDF/S)



Domain	Number of datasets	Triples	%	(Out-)Links	%
Media	25	1,841,852,061	5.82 %	50,440,705	10.01 %
Geographic	31	6,145,532,484	19.43 %	35,812,328	7.11 %
Government	49	13,315,009,400	42.09 %	19,343,519	3.84 %
Publications					
Cross-domain					
Life sciences					
User-generated content	20	134,127,413	0.42 %	3,449,143	0.68 %
	295	31,634,213,770		503,998,829	

More than 30 billion RDF triples as linked **factual knowledge** available ….

Semantic Decision Support



Depending on

- **Application**
- Environment
- Semantic model

… and a large number of **methods** for **ontology-based querying and reasoning**:

- ✓ Semantic **data**
  - ❑ Facetted, Link-Traversal, P2P, Federated search (e.g. with SPARQL1.1)
  - ❑ Stream reasoning (e.g. with C-SPARQL)
  - ❑ Hybrid semantic and statistical analysis
  - ❑ Explanation of results
- ✓ Semantic **services**
  - ❑ Discovery, Selection (Matchmaking)
  - ❑ Composition planning

E Blomqvist (2012): Use of Semantic Web Technologies for Decision Support. *Semantic Web Journal*.

Agent-Based Semantic Decision Support

SHOWCASES IN INFOTAINMENT

Recommender Agents in the Web

Provide **personal decision support:**

What, where, why to buy, watch, read, listen to, etc. ?

by recommending **relevant** items to the user

- pull and/or push mode
- content-based, social, or hybrid (profile, text similarity-based relevance)
- user/item context-sensitive (time, season, location, companion, etc.)

How can **semantics** help here?

Semantic Recommender Agents

Use of semantic model of decision domain

- ❑ User profile and domain ontologies (OWL)
- ❑ Knowledge graph with linked data sources (RDF/S)

to compute **semantic relevance** of items

- ❑ Logical (item) concept subsumption relations
- ❑ Knowledge graph analytical heuristics, etc.

cENTERTAIN.ME
Movies

OOYALA Powered by jinni
Videos

my media Semantic IPTV
TV channels

serum
News

HORST
Music

seevl REINVENTING MUSIC DISCOVERY

✓ **Improved accuracy** compared to non-semantic approaches

✓ **Better explanation** of recommendations

- J Pazos Arias et al. (2012): Recommender systems for the social Web. Springer
- R De Virgilio et al. (2012): Semantic search over the Web. Springer
- E Peis et al. (2008): Semantic recommender systems. Hypertext.net, vol 6

Example: Semantic Relevance

Path-based item relevance heuristic SPrank:

Frequency of **different** user-item **path types** (features) *j*

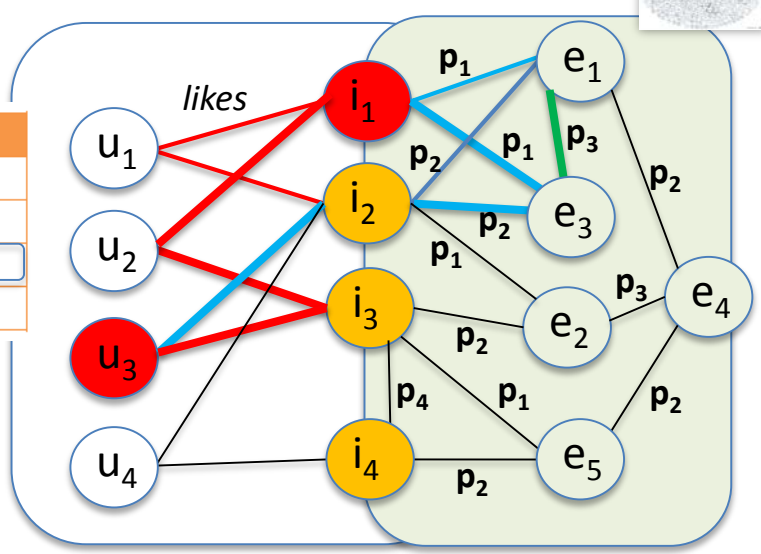
$$\vec{x}_{ui}(j) = \frac{\#\, path_{ui}(j)}{\sum_{d \in D} \#\, path_{ui}(d)} \in R^D$$

Semantic model of decision domain:
Knowledge graph

User profile $\hat{S}$

	I_1	i_2	i_3	i_4
u1	1	1	0	0
u2	1	0	1	0
u3	?	1	1	0
u4	0	1	0	1

u: user, i: item
e: entity (new user/item)
p: property



Semantic relevance feature vector of **item i_1 for user u_3:**

$\boldsymbol{x_{31}}$ = (2/5, 2/5, 1/5), |p|<5

- *collaborative*
  #**path(1)** = (likes,likes,likes): **2**
- *content-based*
  #**path(2)** = (likes,p_2,p_1): **2**
  #path(3) = (likes,p_2,p_3,p_1): **1**
- *hybrid,* |p|>=5
  #path(4) = (likes,p_2,p_1,likes,likes)

➢ Regression-based learning of rank f(x_{ui}): **Higher accuracy than common standards**

(up to **0.6 recall** >> BPRLin, SLIM, SMRMF with test data from MovieLens, Last.fm)

T Di Noia et al. (2013): Top-N recommendations from implicit feedback leveraging Linked Open Data. Proc. ACM 7th RecSys Conf.

For Best Performance: Semantic or Non-Semantic ?

The 1M$ Netflix Prize 2009

Fixed combination of **non-semantic** predictors of movie ratings

- Won the contest but with **low precision** (accuracy $RMSE_n$ 0.8567)
- Not suitable for top-N recommendation

Since 2011: Open contest on learning the best combinations

(Corr.: multi-armed bayesian bandit problem solving)

plista Contest

Current research and development of recommenders:

Make **use of semantic** relations to **avoid cold start** problem, and

to **compensate** for **non-semantic misclassifications.**

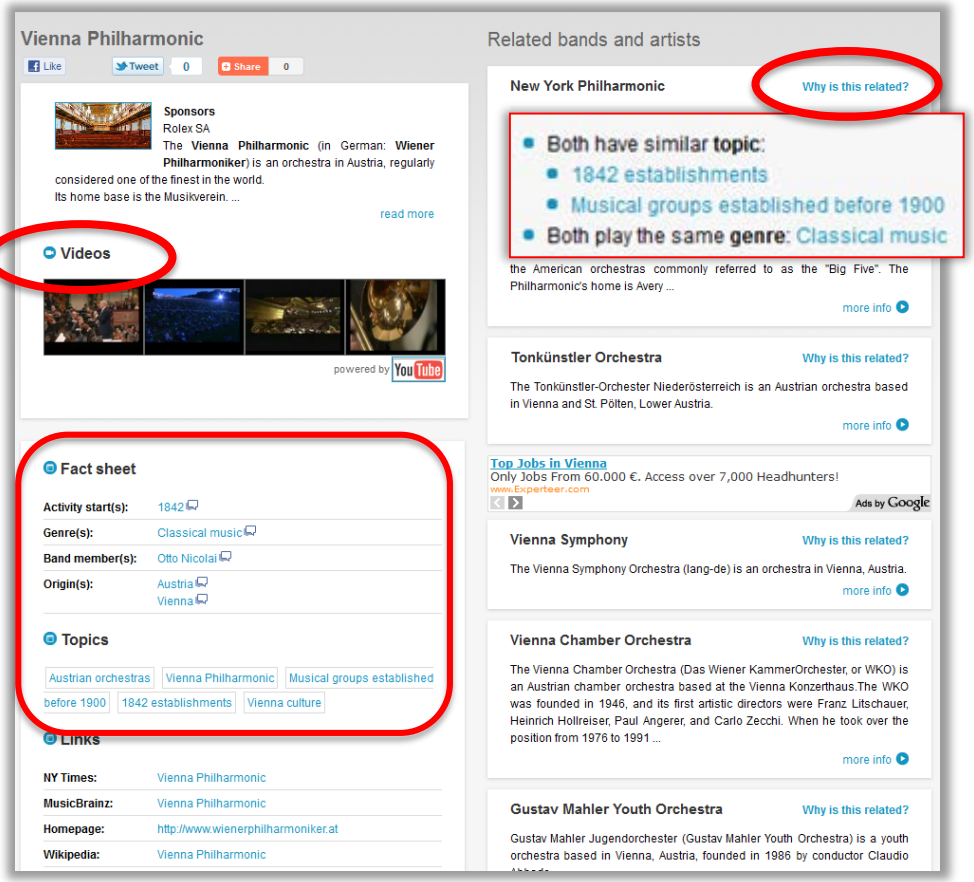
Search for best **hybrid recommender** for given context is still ongoing …

- R Yan et al. (2013): Using semantic technology to improve recommender systems based on Slope One. Springer
- JW Ha et al. (2014): EPE – An embedded personalization engine for mobile users. IEEE Internet Computing, 18(1)

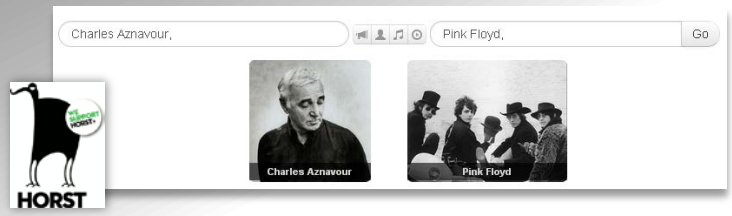
Example: Semantic Explanation

Use of **semantic relevance** methods
to **summarize** the
most relevant properties of
top-ranked items in multimedia panel

… as you know it also from e.g. dbpedia,
Google or Facebook knowledge graph search



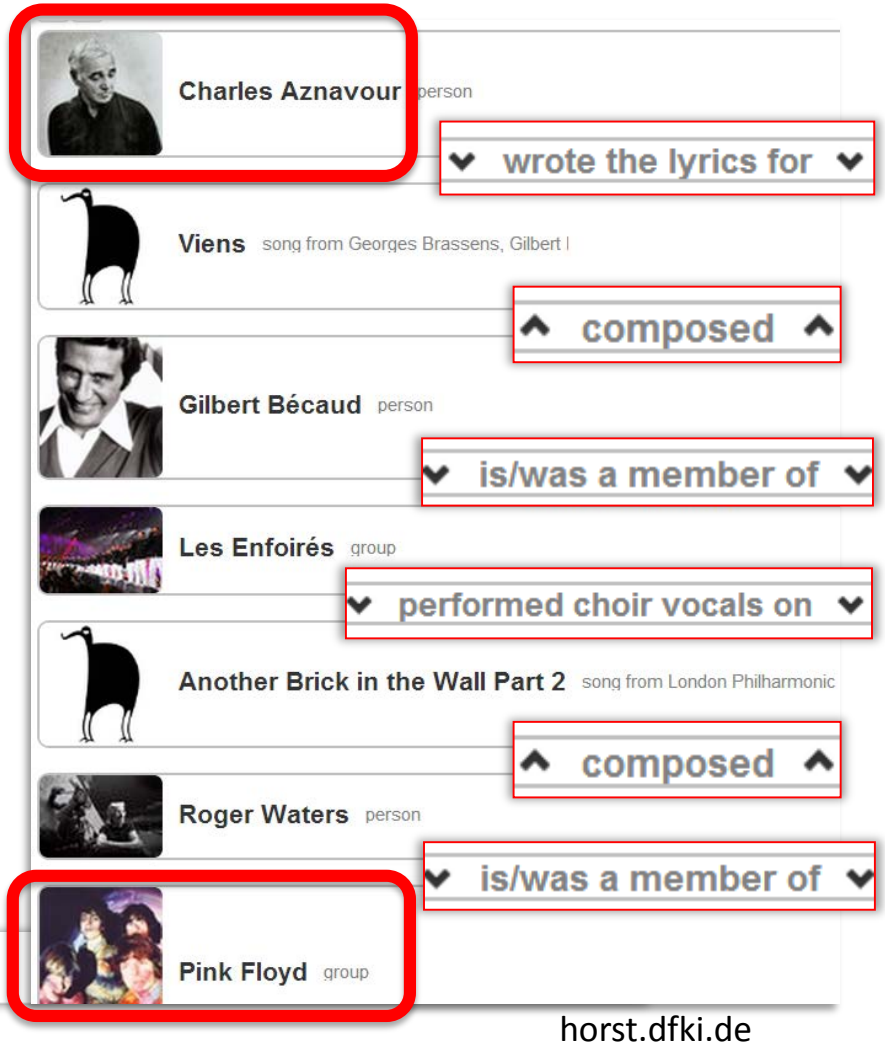
Example: Semantic Explanation (2)



For N-Item **relational** queries:

Display the **shortest item-item paths in the knowledge graph** ….

(Corr. NP-hard Steiner tree problem solution)



…. and **learn** to improve accuracy based on implicit/explicit user **feedback:**

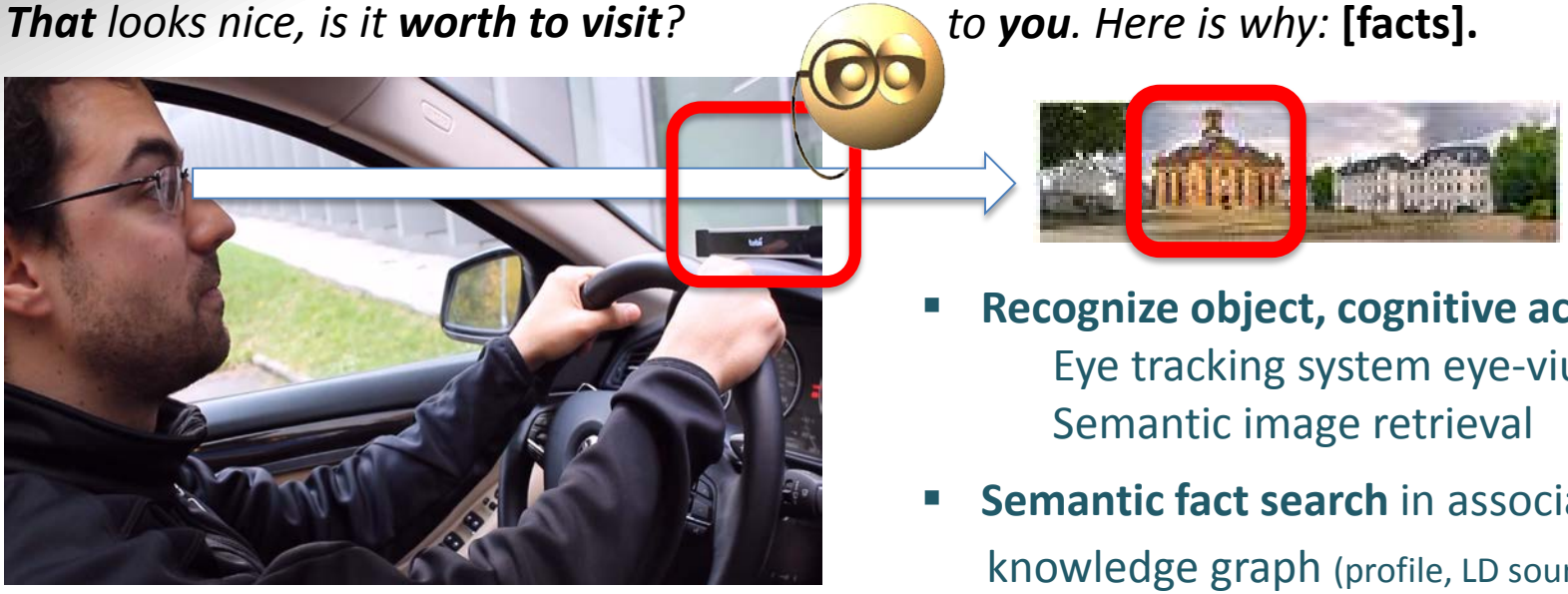
horst.dfki.de

Example: Context-Sensitive

BMW SmartCarAgent provides **personal decision support** to a **driver** based on his **current context**:

That *looks nice, is it* ***worth to visit****?*

Yes, this ***church*** *can be of* ***interest*** *to* ***you****. Here is why:* **[facts].**



- **Recognize object, cognitive activity**: Eye tracking system eye-viu, Semantic image retrieval
- **Semantic fact search** in associated knowledge graph (profile, LD sources)

- **Cognitive activity level constrains presentation** (voice, text on panel, extent of information): Reduced distraction, cognitive overload in driving situation

M Moniri, M Feld, C Müller (2012): Personalized In-Vehicle Information Systems. Proc. 8th IEEE Conf. on Intelligent Environments. Best Demo Award.

We Have That Already in Practice ?

State of the art example for in-car entertainment, since mid 2013

Apple's **Siri** **Eyes Free system** allows drivers

"to make calls, dictate text messages, play music

or podcasts, and **access** everything else

the voice-controlled **virtual assistant** has control over."

Uses **semantic** knowledge graph search for selection of registered data and services

.. but **no personal context-sensitive** action, **no explanation** of results ..

Example: TIFF MyMedia Agent

Provides **personal** and **group decision support** in social media

(1) Semantic P2P search of annotated media data and services

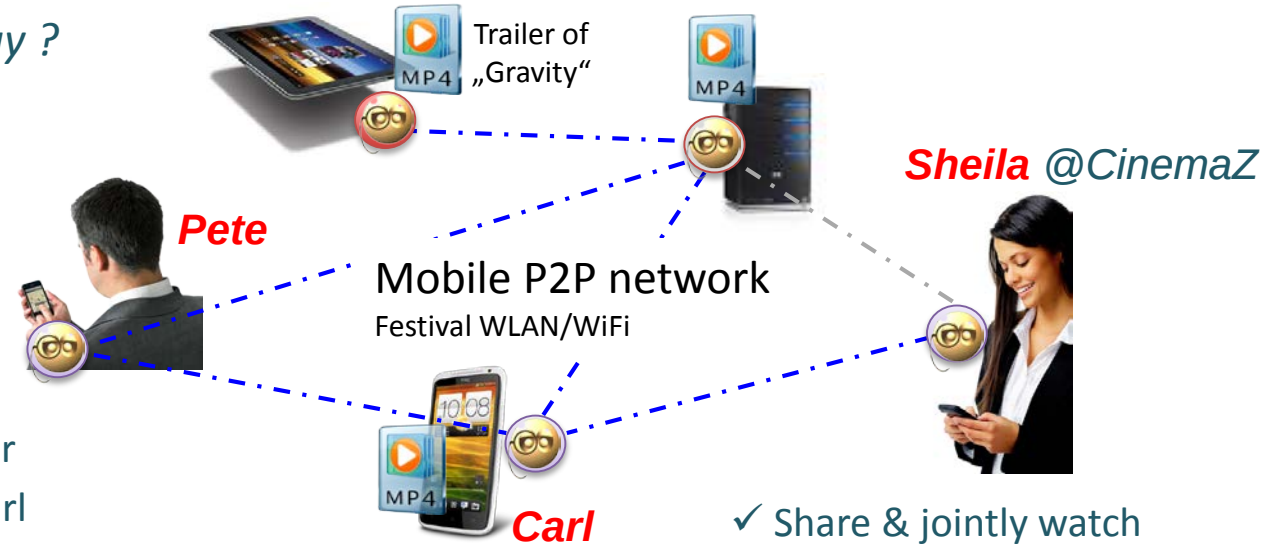
(2) Network-adaptive **real P2P live streaming** of videos

THESSALONIKI INTERNATIONAL FILM FESTIVAL

53rd, 2013

(1) *Any SciFi movies on play ?*

✓ Movie „Gravity“ [Trailer].
Playing next @CinemaZ



(2) *Shall we all go watch it at CinemaZ ?*

✓ Share & jointly watch trailer with buddies Sheila and Carl

So, yes, we like to - but only in a nice cinema .....

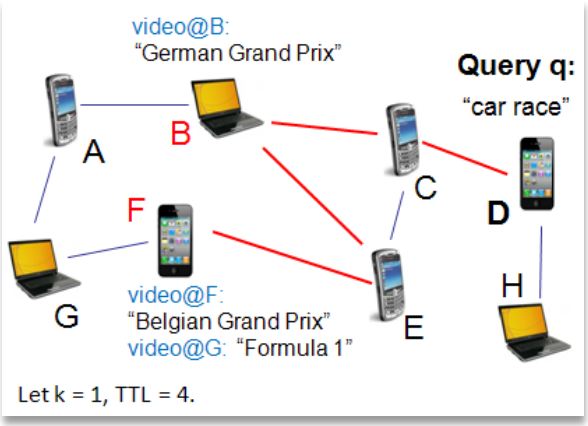
✓ Share & jointly watch **live recording** of CinemaZ with Pete and Carl

EU IP SocialSensor 2011 – 2014 (WP Semantic Middleware; DFKI & U Klagenfurt)

Semantic P2P Search in MyMedia

- Each peer **observes** semantics of query q and traversing items during **k-walker search**
- **Semantic routing** of item query q:

  Shortest path (within TTL) with **maximal** # of peers with **semantic expertise** for the topic of q
  - *Logic-based* semantic relevance of media data (OWL)
  - *Hybrid semantic* media service selection (OWL-S)
- **Dynamic semantic replication** of items (optional)
  - Demand-driven in query topic-based peer groups
  - Maximized utility of replication (semantic gain vs. traffic costs)



D knows expert B (not F) for q.
C knows expert F (not B) for q.
F stands in for G (TTL=0) for q.
Walker q returns from F to D.

- Avg. Precision: **0.82** (1M peers, RPLG networks, random/Zipf), robust
- Real **P2P live streaming** with MPEG-DASH: **4s** latency (4 Nexus7, G2)

X Cao, M Klusch (2013): Proc. 15th IEEE Conference on High-Performance Computing and Communications.

B Rainer et al. (2013): Real-time Multimedia Streaming in Unstructured Peer-to-Peer Networks. Proc. 11th IEEE CCNC Conf.

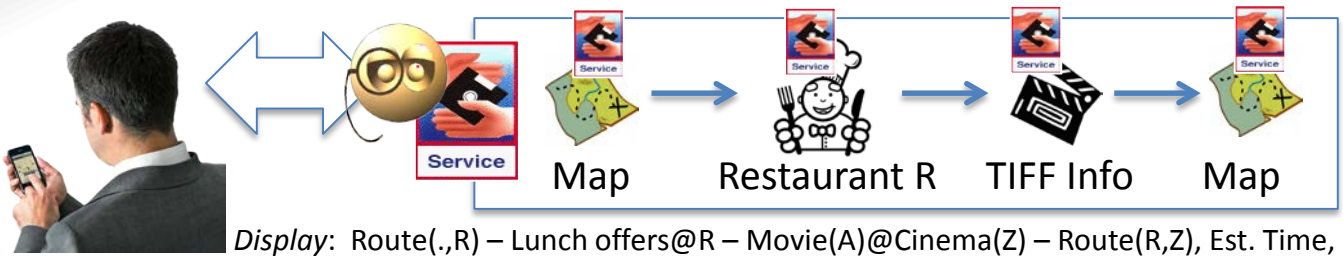
Example: Semantic Service Mashup

TIFF-MyMedia Agent 2.0 with **personal action planner:**

Where to best have lunch on my way to watch movie A in which cinema in time?

THESSALONIKI INTERNATIONAL FILM FESTIVAL

54th, 2014



Display: Route(.,R) – Lunch offers@R – Movie(A)@Cinema(Z) – Route(R,Z), Est. Time, Details.

- Uses profile, context and mobile **semantic service planner** OWLS-Xplan 2.2
- **KPI-driven offloading** of planning processes to (private/TIFF) **cloud**

Other examples @aimashup.org

2013: 50.000 web services [sousuo 4/2013]

2017: 10 billion mobile connected devices

2050: 50 billion things as services [CISCO 2013, W3C XG SSN]

Selected Challenges

- **Usability & Scalability**: *Multimodal, contextual* user interaction for *dynamic, energy-efficient* service selection/planning on *mobiles*

  → HCI, Mobile cloud computing [Fernando+ 2013; Ha+ 2014]

- **Interoperability** across mobile telco providers

  → WebRTC (W3C, IETF) e.g. for web-based (mobile) P2P apps

- **Security & privacy** of data, processes, user/group profiles that are offloaded to cloud or distributed in peer group: *Semantic* inference problem + *technical* security threats

- Semantic-empowered **trusted recommendation**

  → Semantic item/user relevance for (social) trust computation

  [Martin-Vicente et al., 2012]

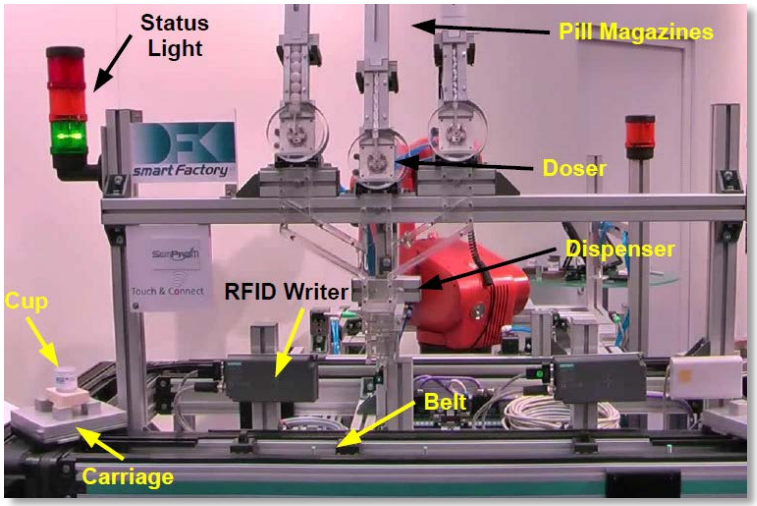
Agent-Based Semantic Decision Support

SHOWCASES IN MANUFACTURING

ISReal Framework for Web-Based Virtual Engineering

Provides **personal decision support** for the commissioning or revision of (parts of) a production line before or during its physical development:

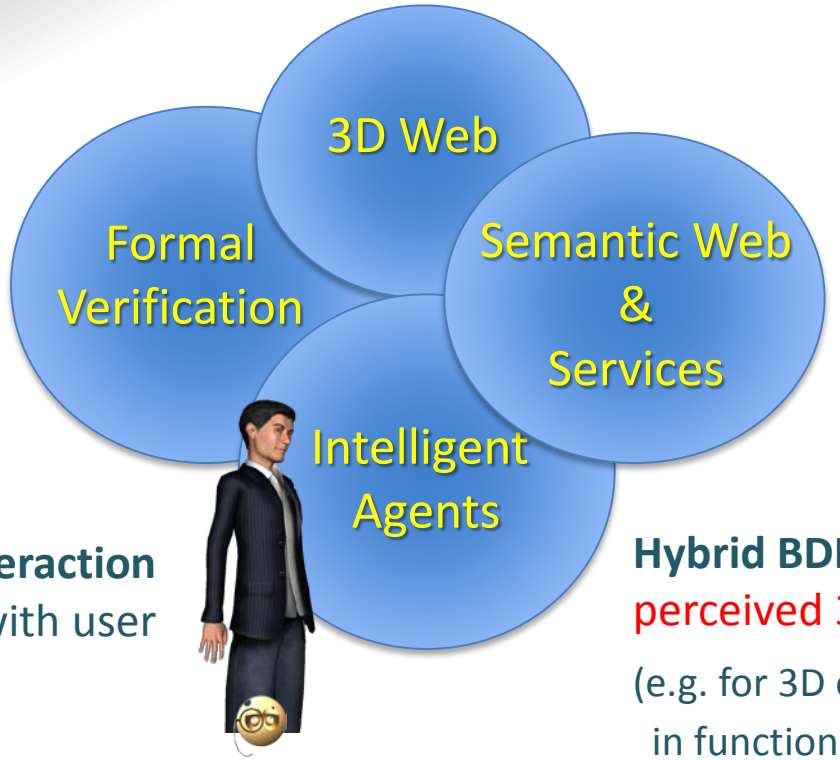
- Functional simulation of physical line in its **annotated virtual 3D model**
- Representation of user as intelligent **avatar** (BDI agent) in 3D scene



Integrated Technologies

Web-based 3D visualization of scenes in **XML3D**

Verification of time-/space-based object properties (safety)



Semantic annotation of 3D scene objects with facts, services

(Common scene ontology in OWL, Object services in OWL-S)

Q/A-based interaction with user

Hybrid BDI action planning on perceived 3D scene semantics

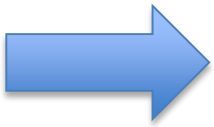
(e.g. for 3D object service composition in functional simulations)

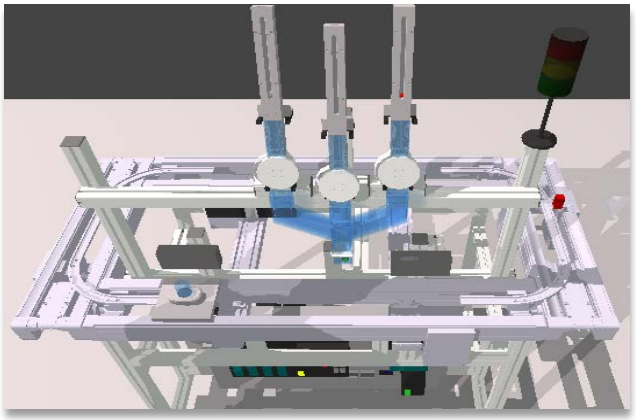
P Kapahnke, et al. (2010): Proc. 9th Intern. Semantic Web Conference (ISWC), LNCS 6414. Springer

Example: Decision Support Scenario

Interactive **query-answering on functionality** of machines:

Can I produce 20 pills with this machine within 30 secs ?





→ **Planning** of machine **services** to reach goal

→ **Time verification** of plan

→ Plan **execution** (functional simulation)

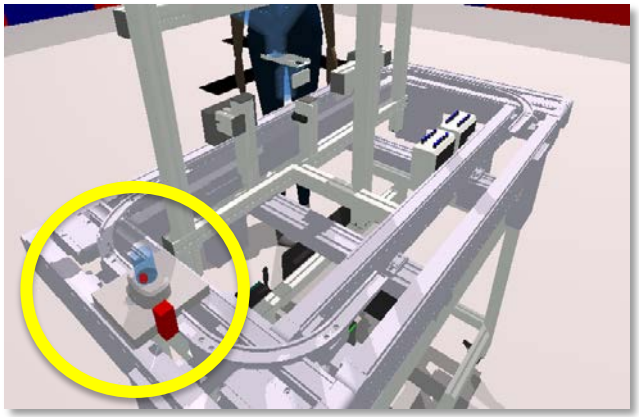
→ **Explanation** (text2speech, animate plan execution)

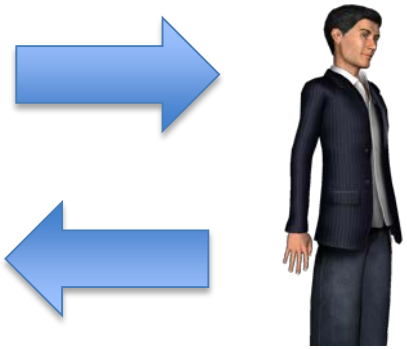
Yes, this pill filling station can do it. I show you how to do it.

Example: Decision Support Scenario (2)

Agent identifies and **explains failures of machines or their handling**, and **creates alternative(s)** for its user:

Why did my handling of this machine fail ?





→ Time-based **verification** of plan execution

→ Visualization of failure trace (**explanation**)

→ Building of **alternative plan** with revised state

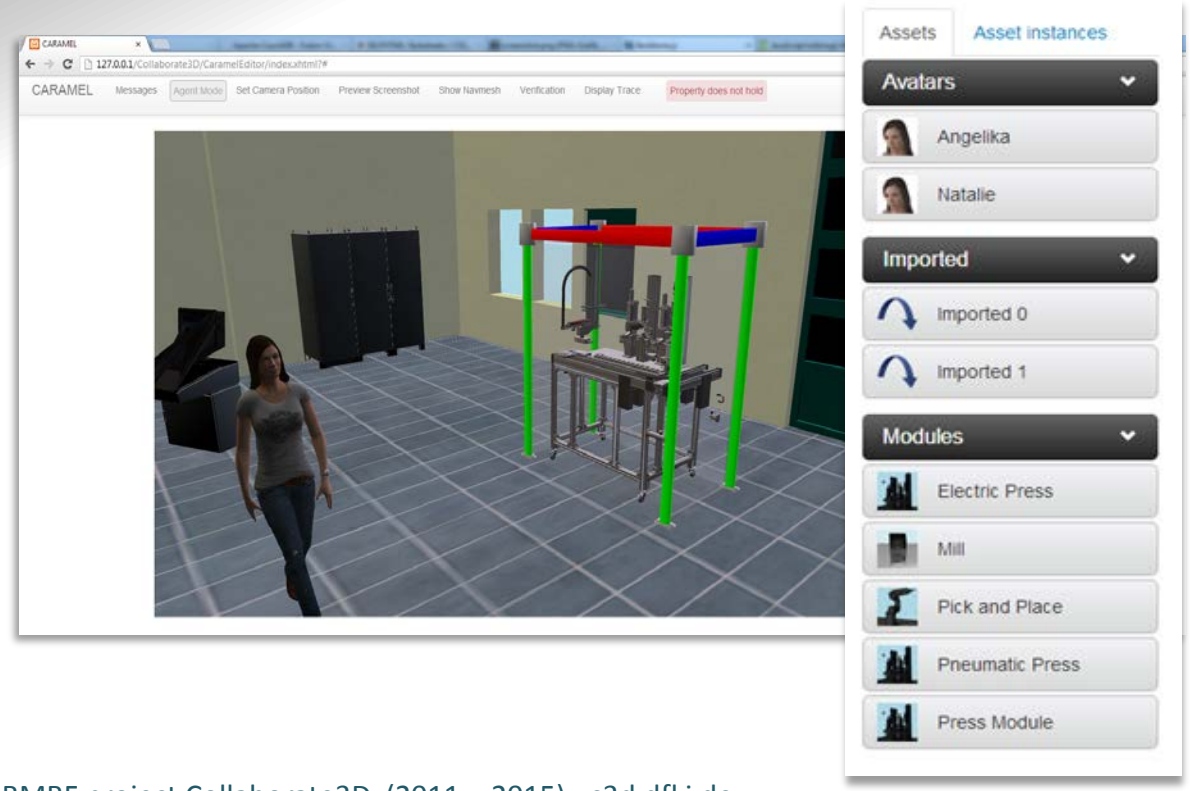
You lifted the carriage stopper too late (11s > 2.5s).

Here is your updated control plan for handling this machine.

C3D Framework for Web-Based Collaborative Engineering

Provides **group decision support** for the design of virtual production lines.

Multiple designers represented by avatars **in shared**, annotated XML3D scene.



- ✓ High-precision local and P2P **search of 3D models**
- ✓ Synchronized **joint view and design** of 3D objects
- ✓ Functional **verification** of designed objects

BMBF project Collaborate3D (2011 – 2015): c3d.dfki.de

I Zinnikus et al. (2013): A Collaborative Virtual Workspace for Factory Configuration and Evaluation. Proc. 9th IEEE CollaborateCom.

Selected Challenges

- **Scalability**
  - → **Web-based** simulation of very large-sized, annotated 3D scenes (>>20 interacting user agents)
- **Collaborative** hybrid BDI planning agents under uncertainty
- **Virtual** condition monitoring of (designed) machines
  - → Semantic **stream reasoning** with CEP and **verification** of real-world sensor data for fault detection/diagnosis in virtual world

Klusch et al. (2013): ICM-Wind: Semantics-empowered CM of wind turbines. ACM SAC

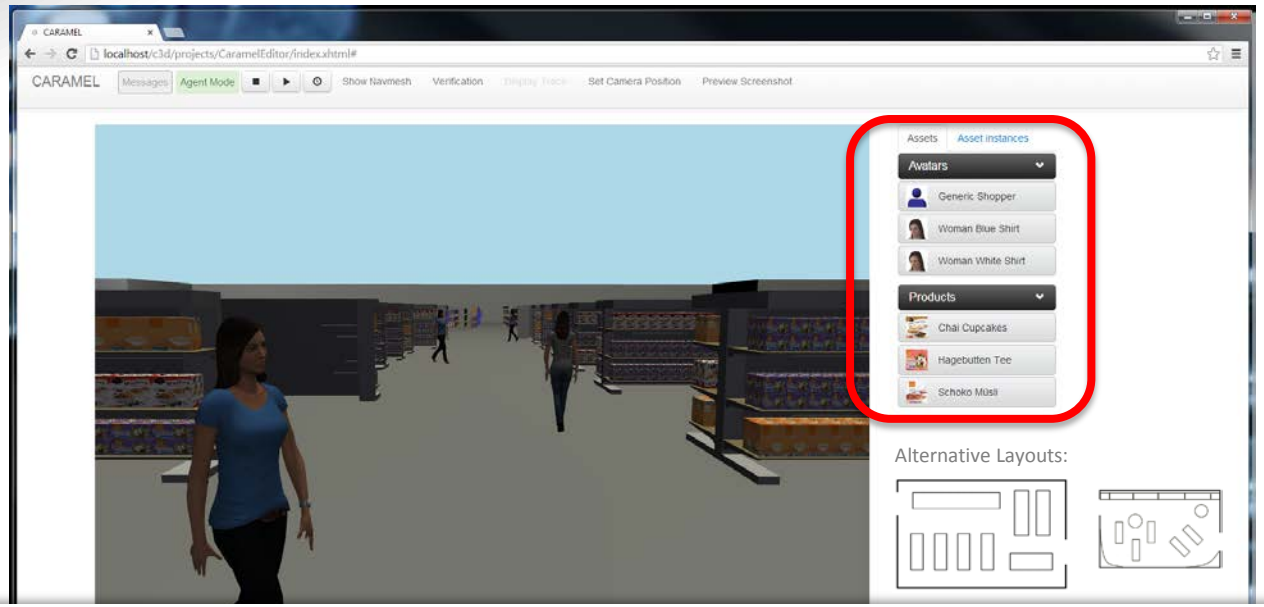
BMBF project INVERSIV (2015 – 2018), EU IP OSMOSE (2013 – 2016)

Agent-Based Semantic Decision Support

SHOWCASES IN SMART RETAIL

CARAMEL:
Virtual 3D Design of Store Layouts

Provides **personal decision support** for choosing the right layout of retail stores:
How to best position the shelves to increase sales for which types of customers ?



Based on
C3D Framework,
ongoing.

Simulation of preset types of **customers** in **annotated 3D layout as avatars** (BDI agents) with type-specific capabilities and goals

- different perception and wayfinding strategies
- different goals: max duration of visit, path length to, max price of prefered products

ADIGE: Smart Re-Ordering of Goods

Provides **personal decision support** for manager for re-ordering of goods:

When to re-order from which provider ?

Store management dashboard | Instrumented store | Process modelling tool

Problem: Service-based **process model** for re-ordering can **change** or **become invalid at any time** due to changes in services performance, availability, prices

✓ ADIGE **agent adapts** the **annotated** process model (OWL) to these changes by **semantic selection** and **re-planning** of actual process services (OWL-S)

DemoVid

CeBIT 2014

Take-Home Messages

For decision support, **agents can make use of semantics** to

✓ facilitate **semantic** data and service **interoperation**

✓ perform **more precise search** for relevant items

✓ **create** and recommend **more accurate alternatives**

in a **more context-sensitive**, **explanatory** way.

Many **agent-based semantic decision support apps**

in various domains **already available or in development**.

Main **challenges**: **Scalability, usability, privacy and trust**

Special Thanks

Intelligent Information Systems (I2S) Research Team

@ DFKI Agents and Simulated Reality Department, Saarbrücken

Manuel Anglet
Bastian Blankenburg
Xiaoqi Cao
Josenildo Costa Da Silva
Andreas Frische
Mostafa Hosseini
Matthias Klusch (Head)
Patrick Kapahnke
Christian Mathieu
Ankush Meshram
Prashant Rao
Felix Standke
Ingo Zinnikus

Visit us at **www.dfki.de/~klusch/i2s**

Thank you for your attention !

Questions ?

klusch@dfki.de

www.dfki.de/~klusch