Context-Aware Decision Support in Dynamic Environments: Theoretical & Technological Foundations

Prof. Alexander V. Smirnov (smir@iias.spb.su)

Head of Computer Aided Integrated Systems Laboratory (CAIS Lab),
St.Petersburg Institute for Informatics and Automation
of the Russian Academy of Sciences (*SPIIRAS*)

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Outline

- Facts about CAIS Lab

- Introduction
- Case Study: Scenario
- Context-Driven Methodology (Theoretical Foundations)
- Technological Foundations
- Case Study (Fire Response, e-Tourism)
- Conclusion

St.Petersburg Institute for Informatics and Automation (SPIIRAS)

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Russian Academy of Sciences (RAS)

- Founded in 1724
- The research umbrella organization of the Russian Government
- 436 units (Research Institutes and Centers)
- 95,000 personnel: 48,500 Researchers (10,000 D.Sc., and 24,500 Ph.D.)

St.Petersburg Institute for Informatics and Automation (SPIIRAS)

- Founded in 1978
- Only 1 Russian Academy of Science Institute operating in Northwest Russia in Computer Science discipline
- 161 Researchers (38 D.Sc., and 59 Ph.D., 34 Ph.D. students, 1 PostDoc)
- Grants Ph.D and Dr.Sc. (Technical) degrees

CAIS Laboratory: Financial Support (2007-2013)

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Russian Academy of Sciences

- 6 projects

Ministry of Education & Science, Russia

МИНИСТЕРСТВО ОБРАЗОВАНИЯ И НАУКИ
РОССИЙСКОЙ ФЕДЕРАЦИИ

- 3 projects

Russian Basic Research Foundation

Russian Humanitarian Scientific Foundation

РФФИ

- 30 grants

- 1 grant

- FP6 IST – 1 project (IP)
- ENPI-Karelia /Finland - 1 project

Bundesministerium
für Bildung
und Forschung

- 1 grant

NOKIA
Connecting People

- 5 projects
- 1 grant

FESTO

- 10 projects

STINT

The Swedish Foundation for International Cooperation in Research and Higher Education

- 2 grants

SI.
Svenska institutet

- 2 grants

Introduction: Cyber-Physical Systems (1/2)

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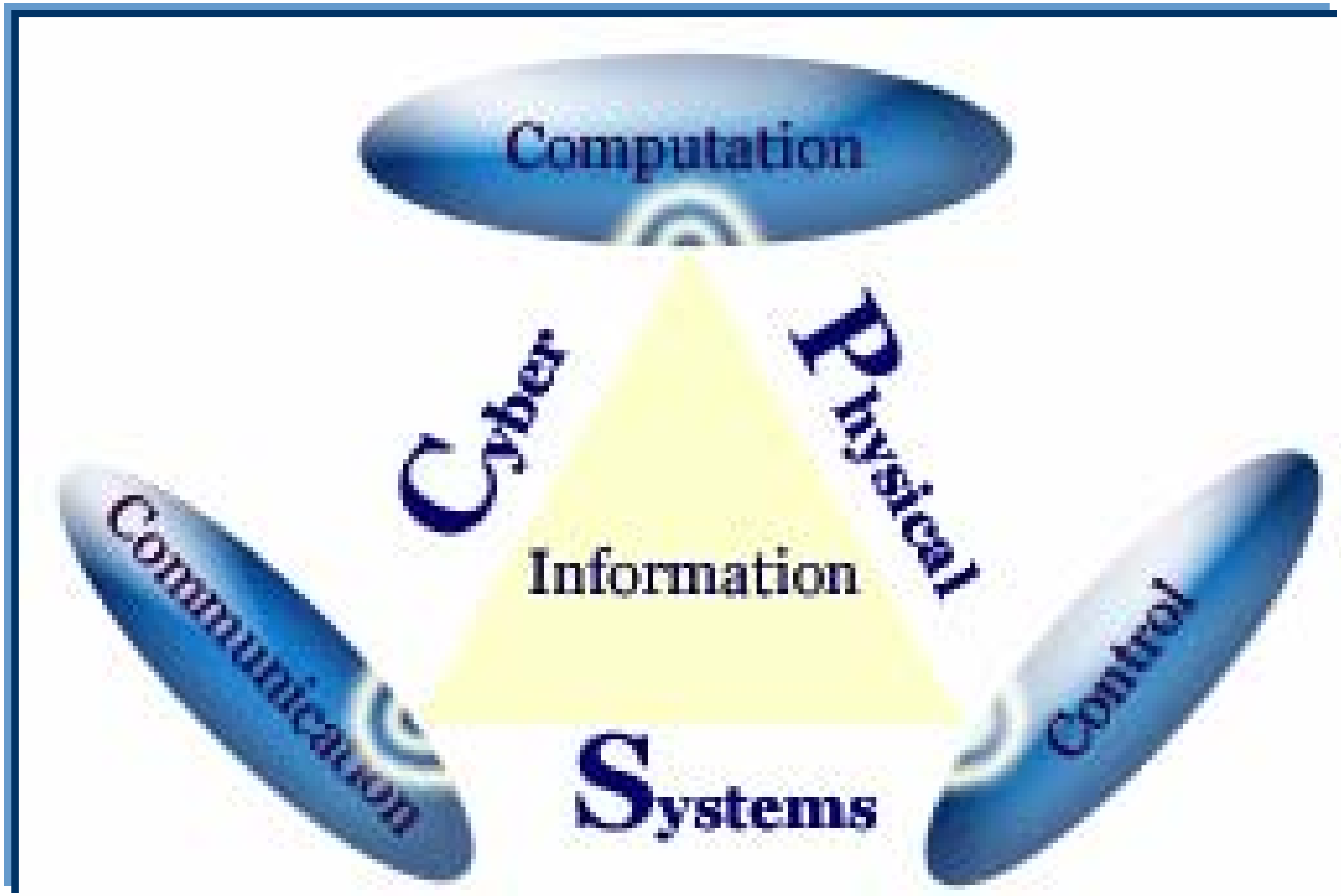

CPS is a tight integration of physical systems and cyber (IT) systems interacting in real time

Introduction: Cyber-Physical Systems (2/2)

- rely on communication, computation and control infrastructures consisting of several levels for both the physical and the IT-part
- integrate sensors, actuators, computational resources, services or communication facilities
  - multitude of component types and changing application environments
- require approaches for managing the variability at design time and the dynamics at runtime

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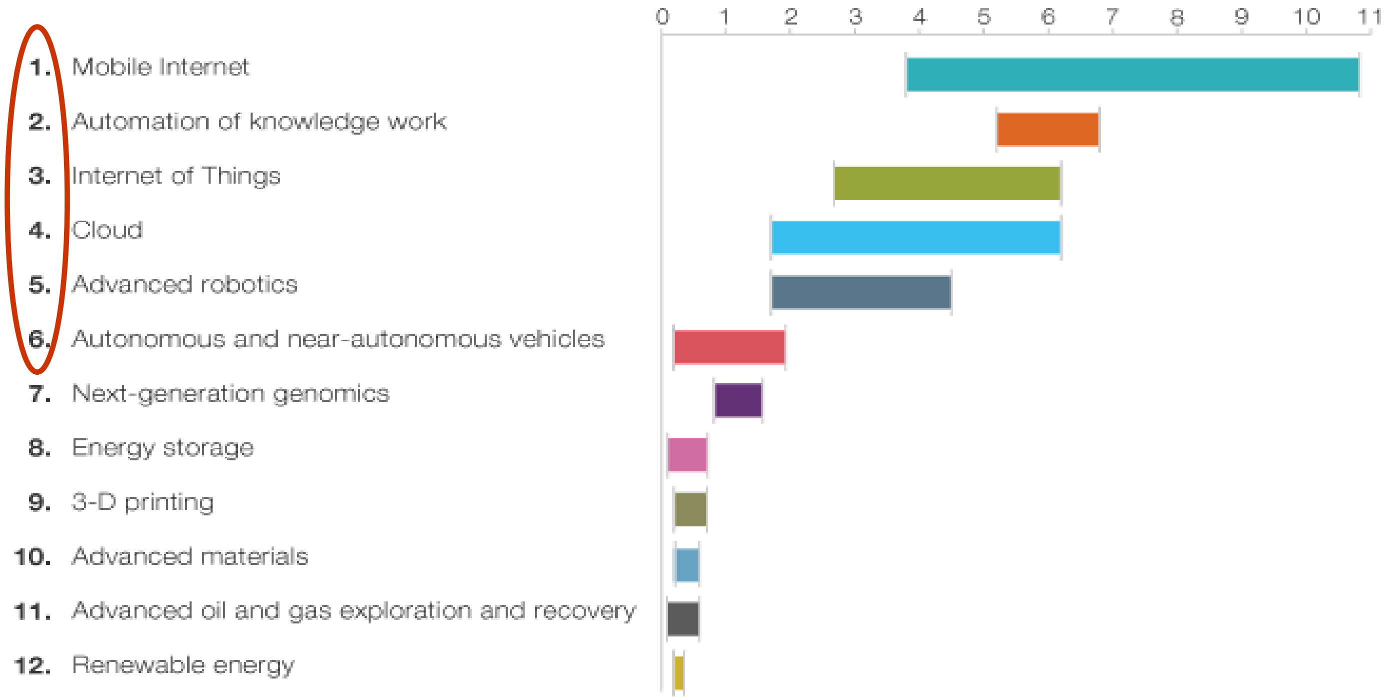
Introduction: Top 12 Technologies by McKinsey Global Institute (May 2013)

A gallery of **disruptive technologies**

Estimated potential economic impact of technologies across sized applications in 2025, $ trillion, annual



SOURCE: McKinsey Global Institute

Notes on sizing: These economic impact estimates are not comprehensive and include potential direct impact of sized applications only. They do not represent GDP or market size (revenue), but rather economic potential, including consumer surplus. The relative sizes of technology categories shown do not constitute a "ranking," since our sizing is not comprehensive. We do not quantify the split or transfer of surplus among or across companies or consumers, since this would depend on emerging competitive dynamics and business models. Moreover, the estimates are not directly additive, since some applications and/or value drivers are overlapping across technologies. Finally, they are not fully risk- or probability-adjusted.

Source: Report MGI "Disruptive technologies: Advances that will transform life, business, and the global economy" (May 2013)
http://www.mckinsey.com/insights/business_technology/disruptive_technologies

Introduction: Network-Centric Operations in Dynamic Environment

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Network-Centric Operations exploit information and network technologies to integrate widely dispersed human *decision-makers*, networking *sensors*, and *resources* into a highly adaptive, comprehensive *network-centric environment* to achieve shared *situation* awareness and *unprecedented mission* effectiveness by efficient linking *knowledgeable components* in the dynamic environment (cyber-physical-social space)

Technologies

- Sensor Networks (Data Gathering)
- RFID (Identification)
- GPS (Localisation)
- Wi-Fi & Mobile Phones (Communication)
- Portable & Embedded Devices (Data Processing)
- Smart Space
- Web-Based Communities
- Web-Services

Introduction:
Application Domain "Dynamic Logistics"

- **Disaster Response (to emergency situations, catastrophic events, natural disasters, etc.)**
- **E-Tourism**
- Intelligent transportation systems
- Build-to-order Supply chain management & e-Business
- Coalition health service logistics support
- …

Introduction: Domain Specificity

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- The practice shows that one of the most difficult steps in responding for such situations is providing for *the right relief* supplies to the people in need *at the right time*
- Usually disaster relief and evacuation tasks involve a large number of different *heterogeneous teams (sometimes multinational),* which have to collaborate in order to succeed.
- Such organization (networked organization) requires *intensive information exchange* in order to achieve necessary level of the situational awareness, create ad-hoc action plans, have continuously updated information.
- Quality of decision making depends upon *the quality of information at hand*
- *User-centric decision support* is of high importance.

Introduction: Decision Making Issues in Dynamic Environments

- scenario-based information management for operation preparing related to *a situation;*
- context-aware interoperability of operation participants based on *common knowledge representation model;*
- on-the-fly decision support assistance for participants (users) based on *Web-services.*

Introduction: Context-Aware Decision Support Motivation

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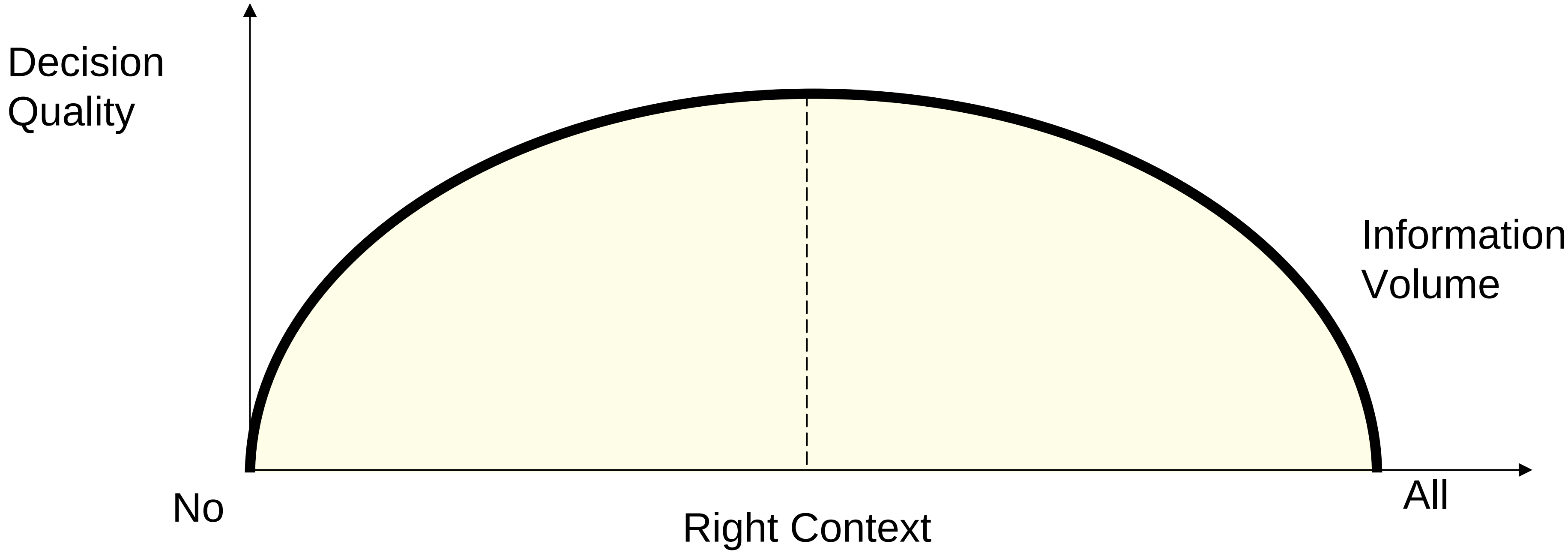

- 50% of the problems in the world result from *people using the same words with different meanings.*
- the other 50% of the problems results from *people using different words with the same meaning.*

Source: Kaplan S. The Words of Risk Analysis, *Risk Analysis*, Vol.17, N 4, August 1997

Introduction: Ontology Definition

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- Ontology is an explicit specification of a *structure* of a certain domain
- Ontology includes a *vocabulary* for referring to a subject area, and a set of logical statements expressing the *constraints* existing in the domain and restricting the interpretation of the vocabulary
- Ontology provides a vocabulary for representing and communicating knowledge about some topic, and a set of *relationships* and *properties* that hold for the *entities* denoted by that vocabulary

Source: Foundation for Intelligent Physical Agents (FIPA), www.fipa.org

Introduction: Context Definition

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- *Context* is any information that can be used to characterize the *situation* of a component, where a component can be a *person, place, physical or computational object.*

- For problem solving *context is what constraints a problem solving without intervening in it explicitly*.

Resource:

Brézillon P., “Context in problem solving: A survey”, *The Knowledge Engineering Review*, vol. 14, no. 1, 1999, p. 1—34.

Introduction: Core Message

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- Contextual interpretation & integration of available mission-focused information & knowledge for decision making is a key point to achieve effectiveness of network-centric operation management based on the **Knowledge Logistics Tenet**:

“The right knowledge from right sources in the right context to the right person in the right time for the right purpose (operational situation)” (*)

Resource (*):

- Smirnov A., Pashkin M., Chilov N., Levashova T. Haritatos F. (2003) Knowledge Source Network Configuration Approach to Knowledge Logistics. International Journal of General Systems, 2003, 32 (3), pp. 251—269.

Case Study: Scenario

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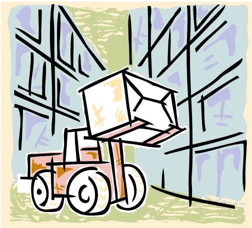
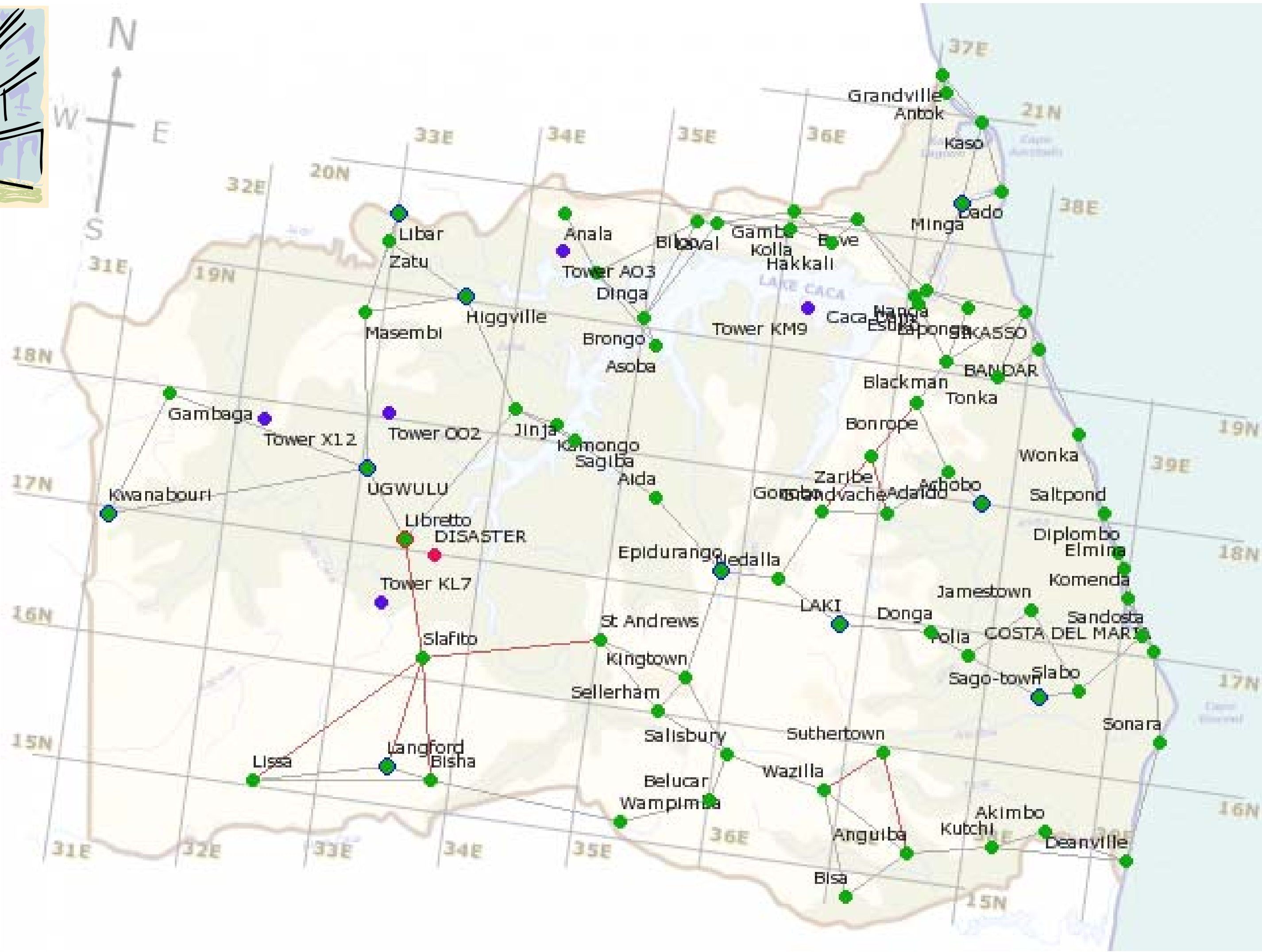


Suppliers



Case Study: Scenario

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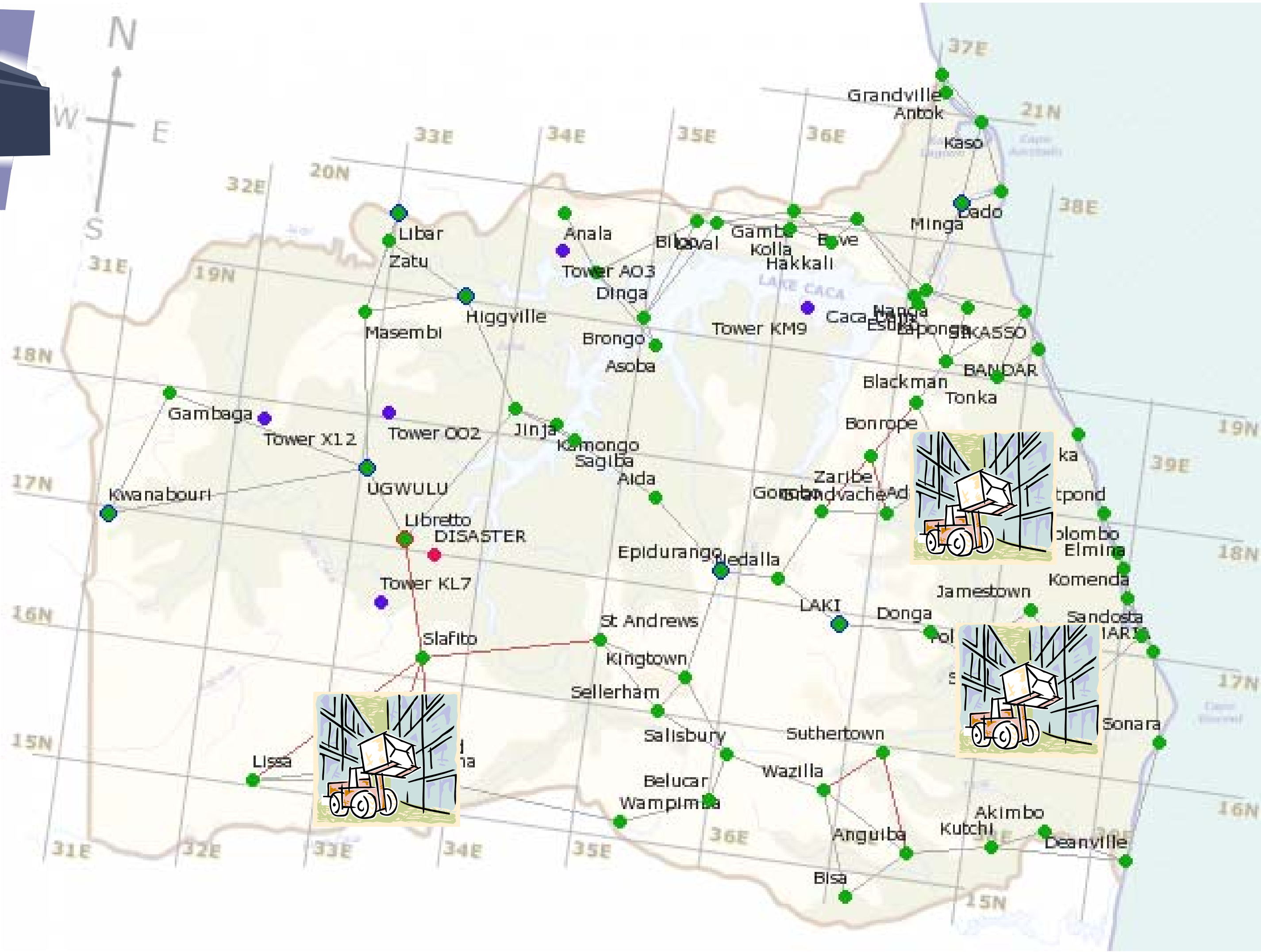
Hospitals



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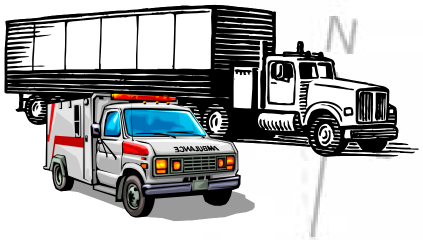
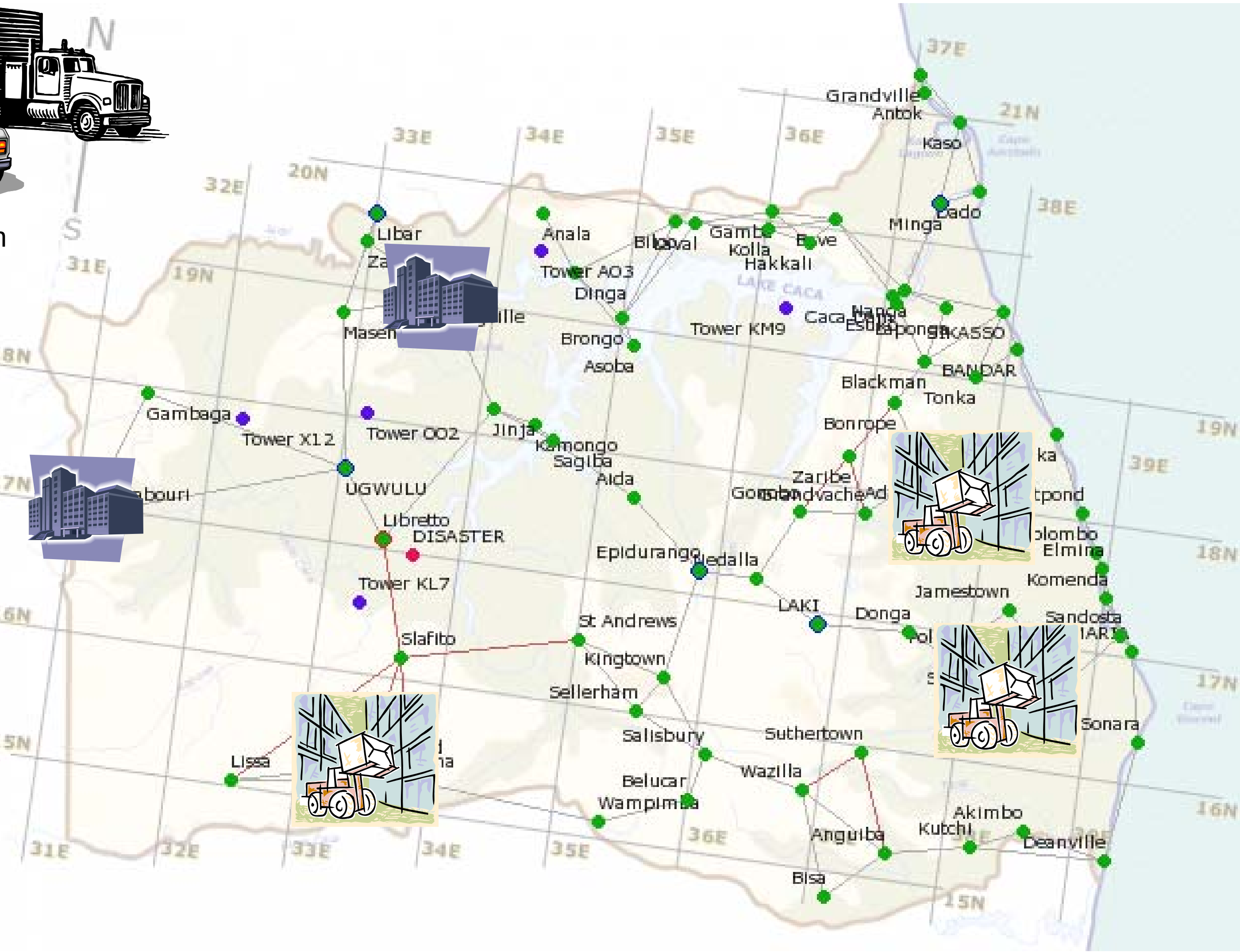
Case Study: Scenario



Transportation Facilities



Case Study: Scenario

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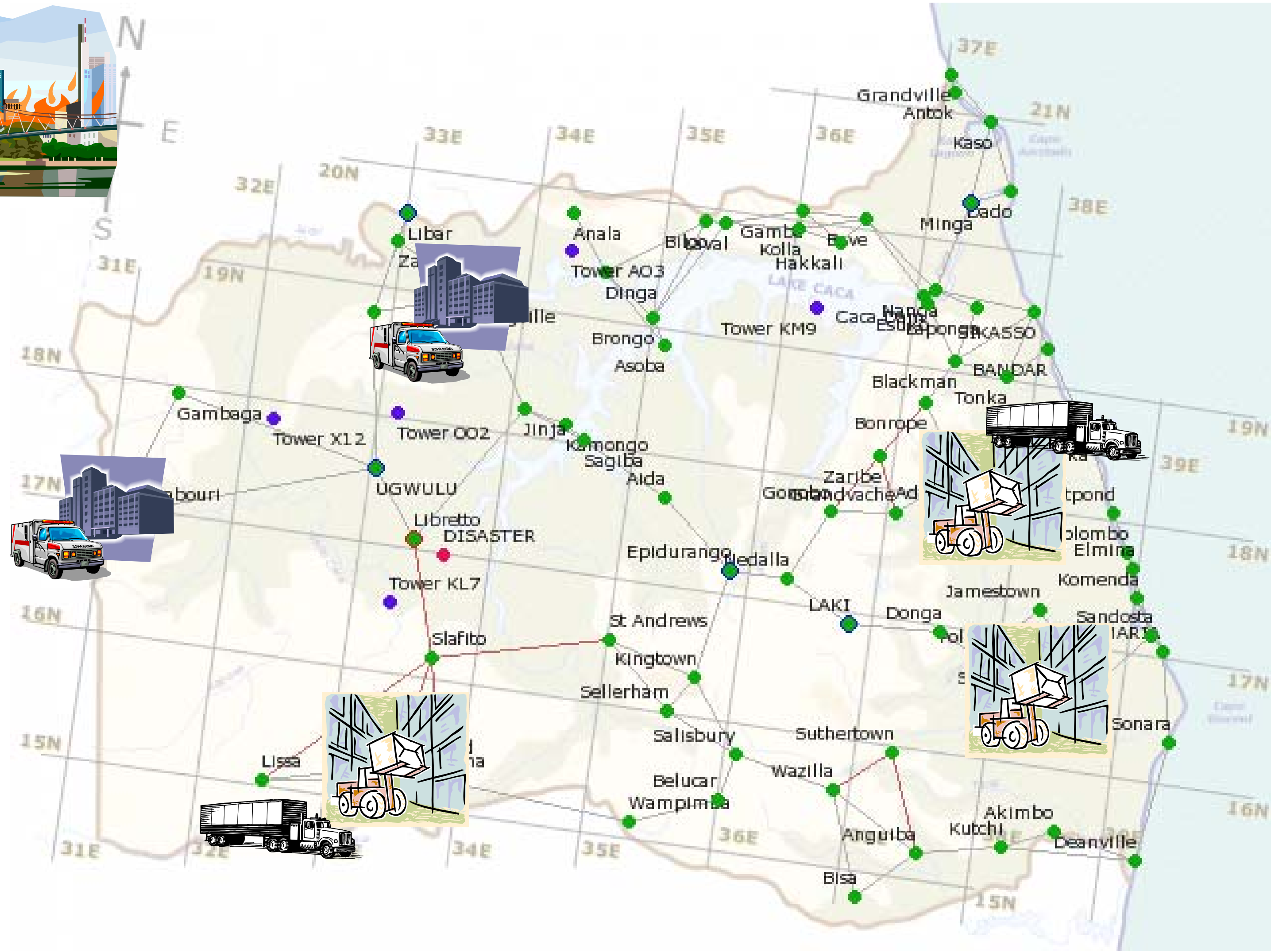
Disaster



Case Study: Scenario

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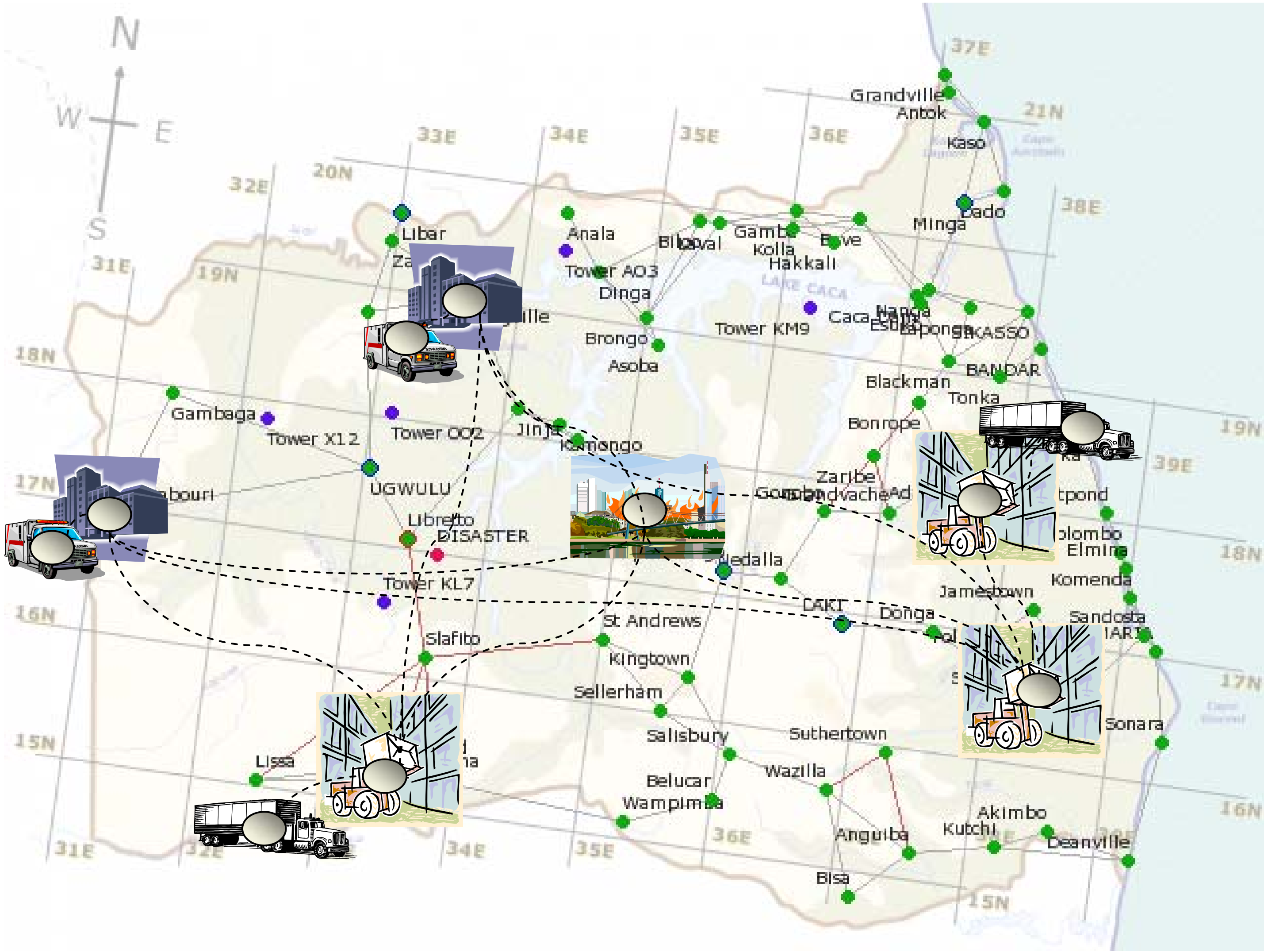
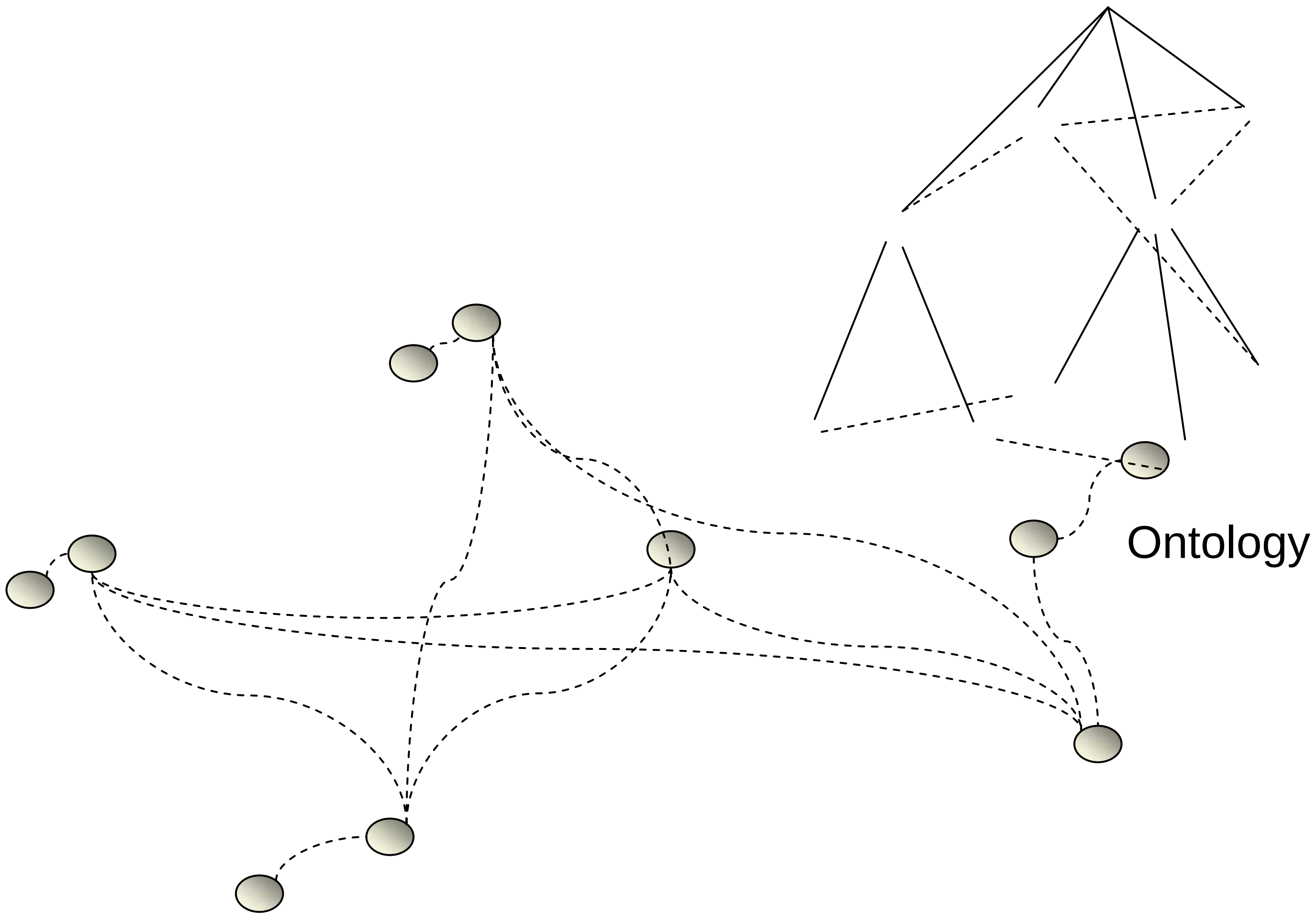


Case Study: Scenario



Case Study: Scenario

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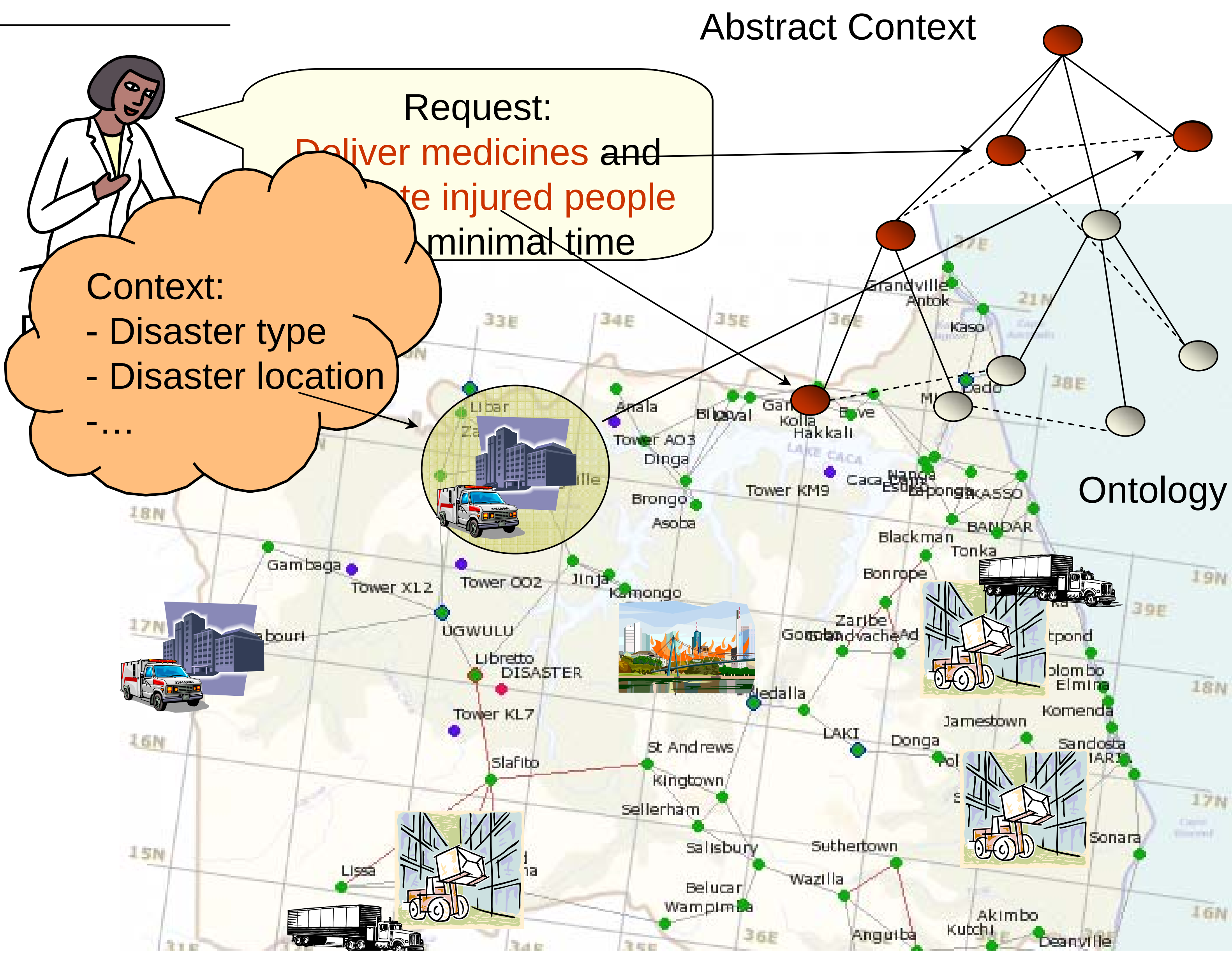

Case Study: Scenario

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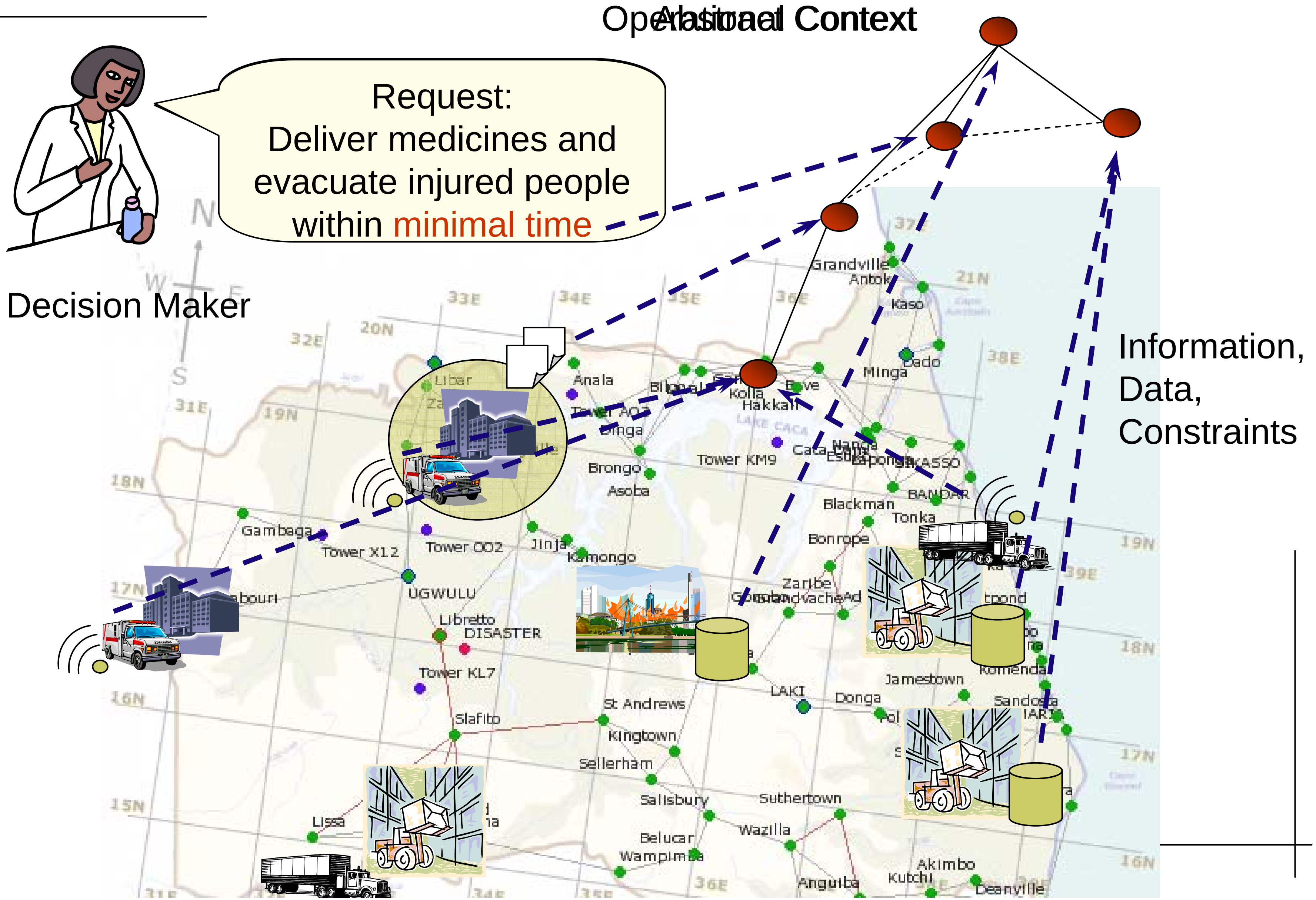

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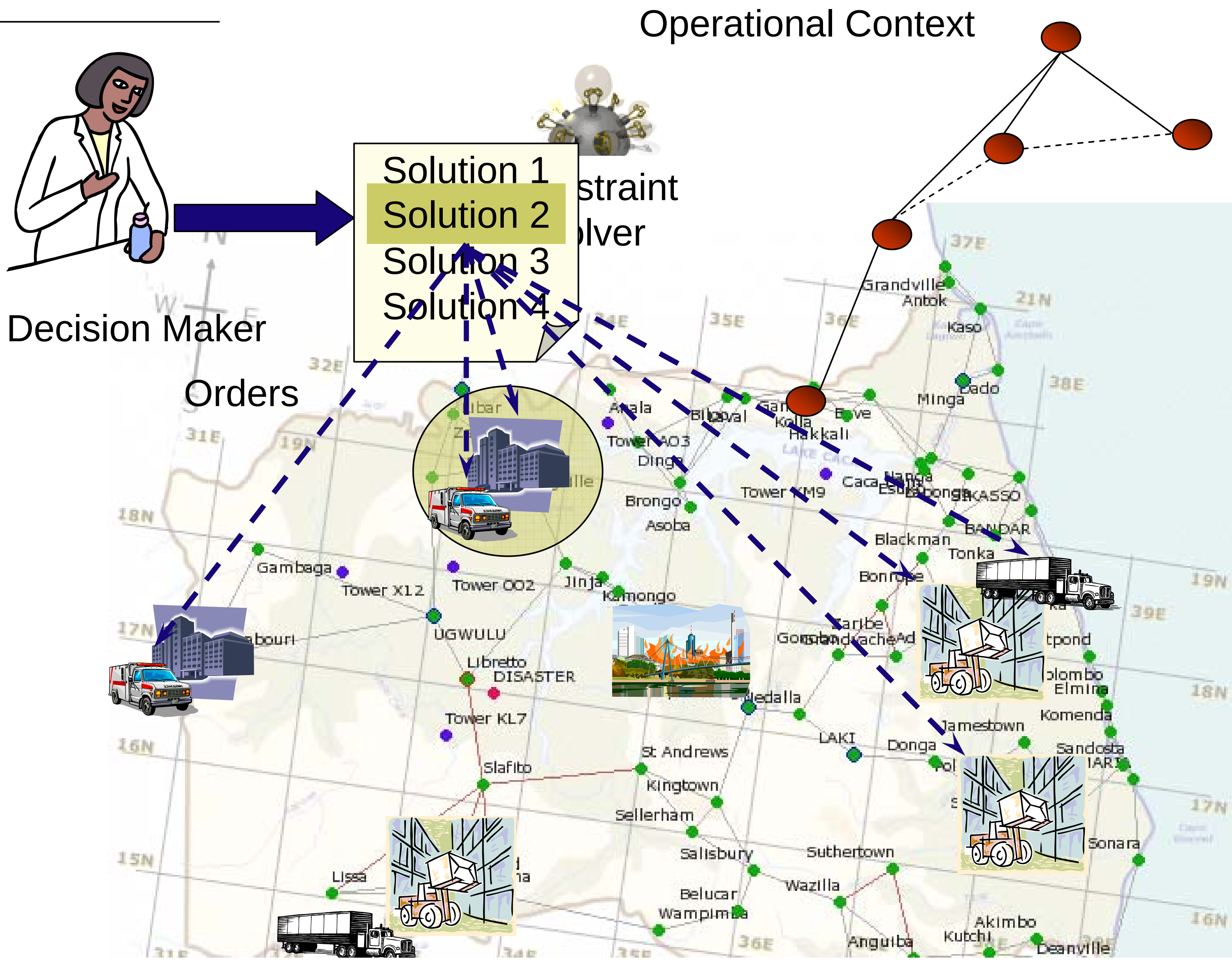
Case Study: Scenario



Case Study: Scenario

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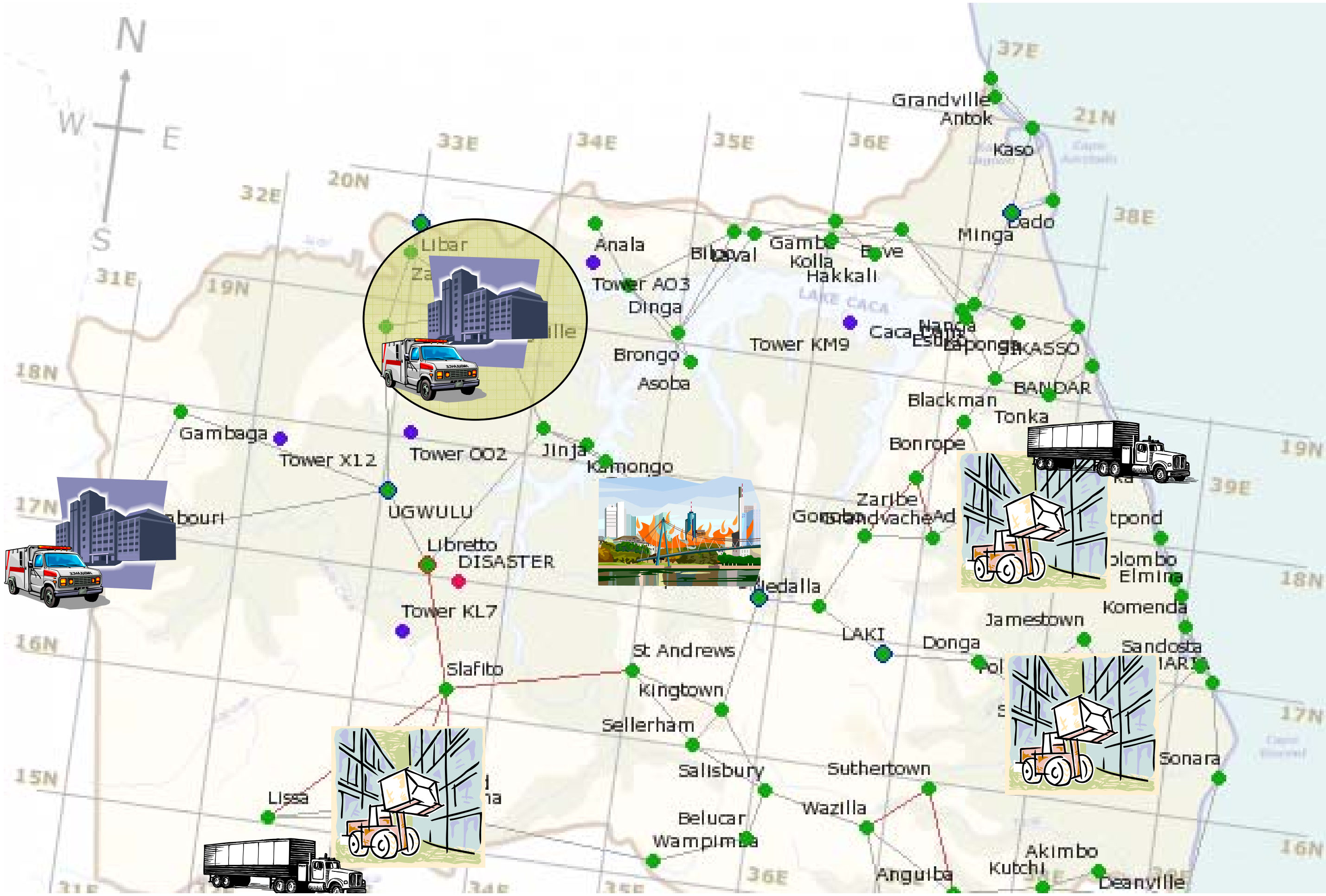

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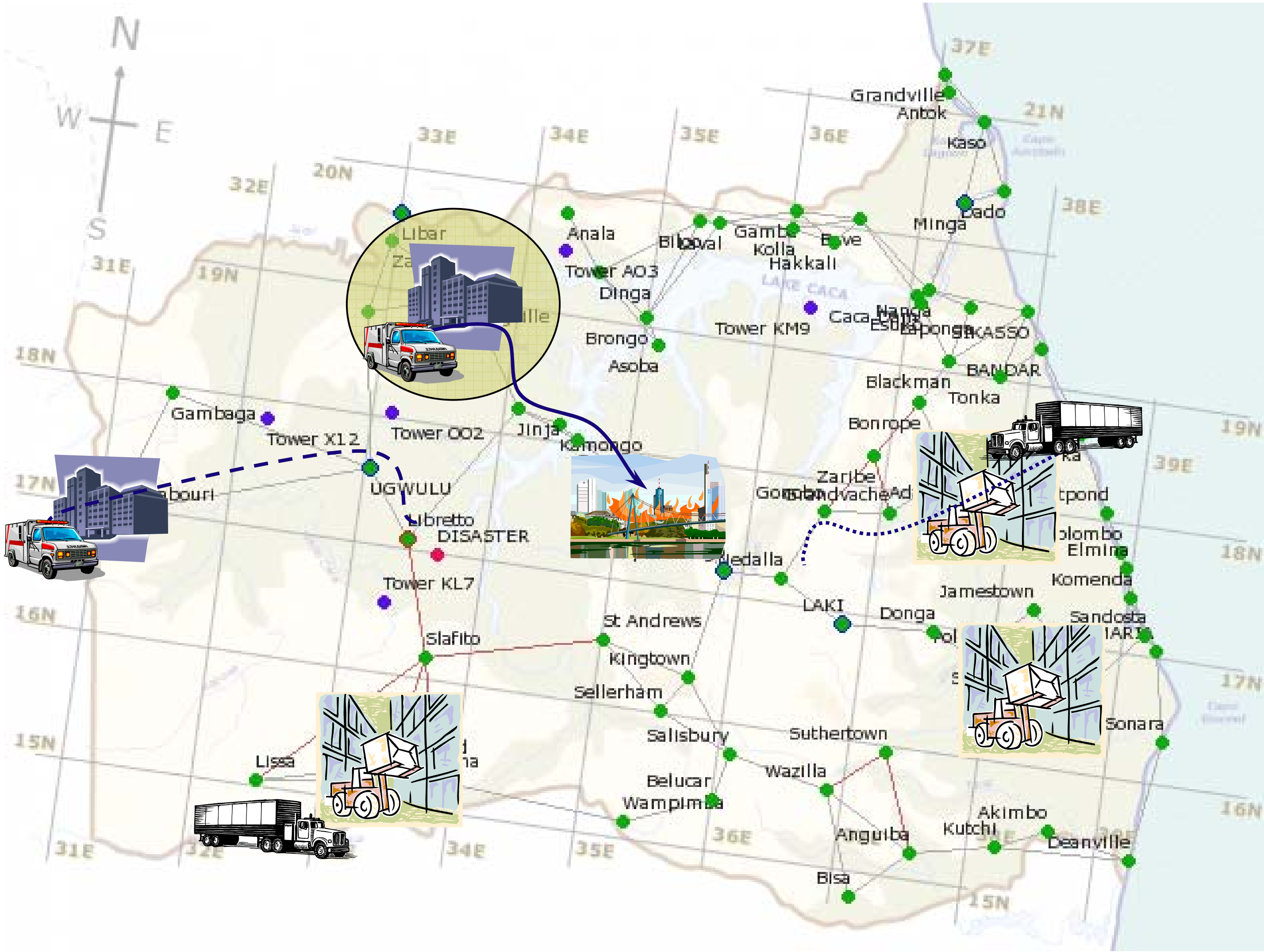

Case Study: Scenario

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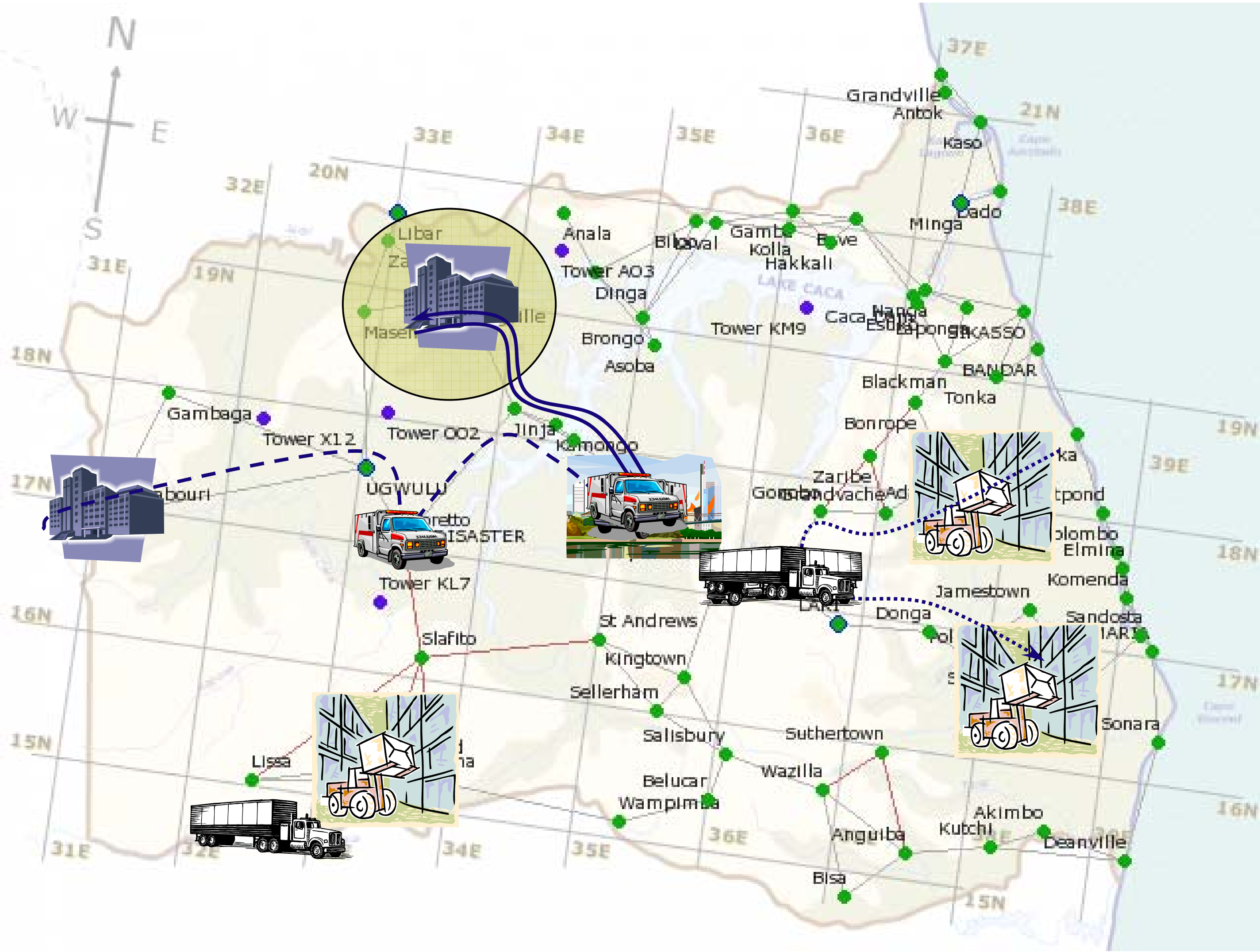

Case Study: Scenario

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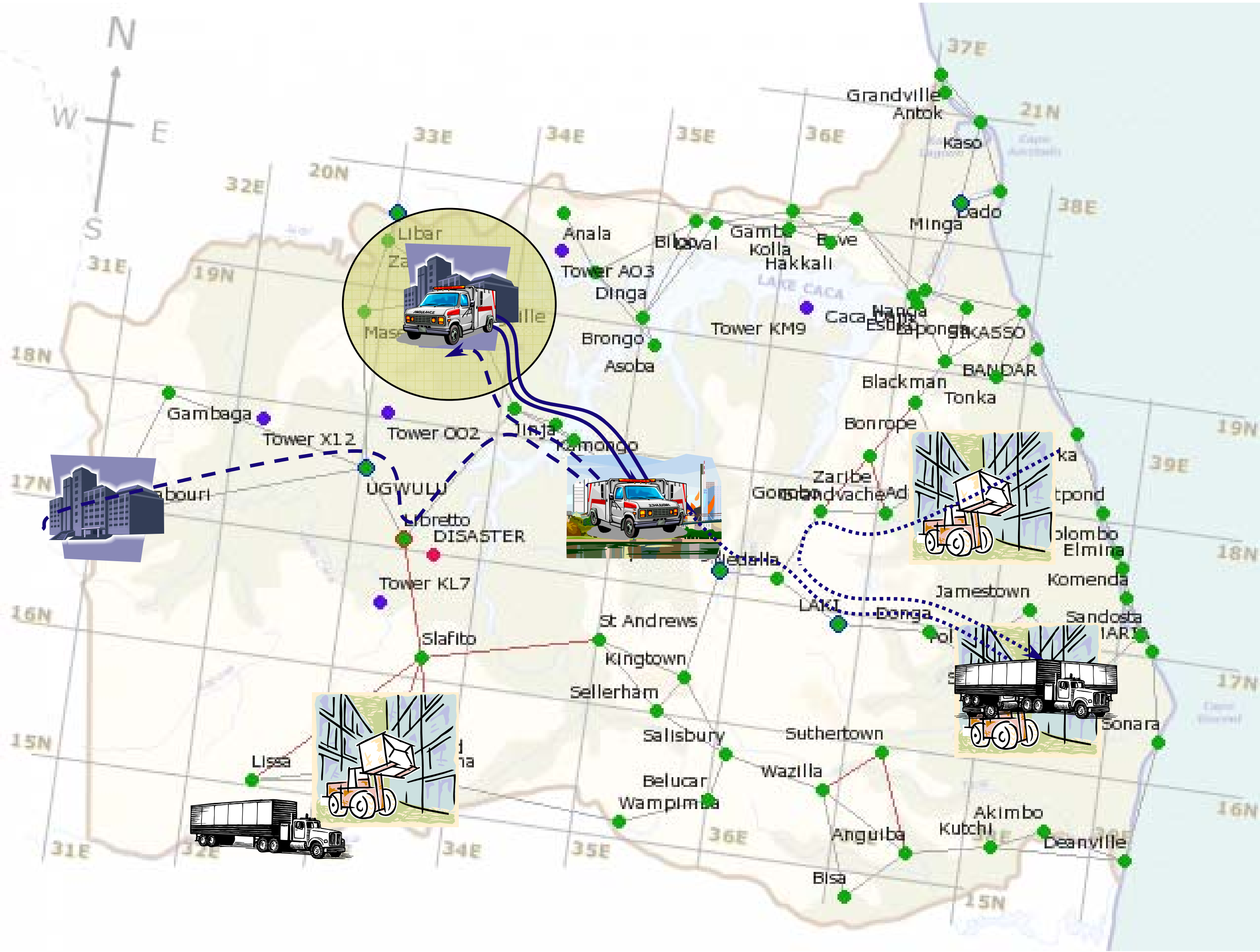
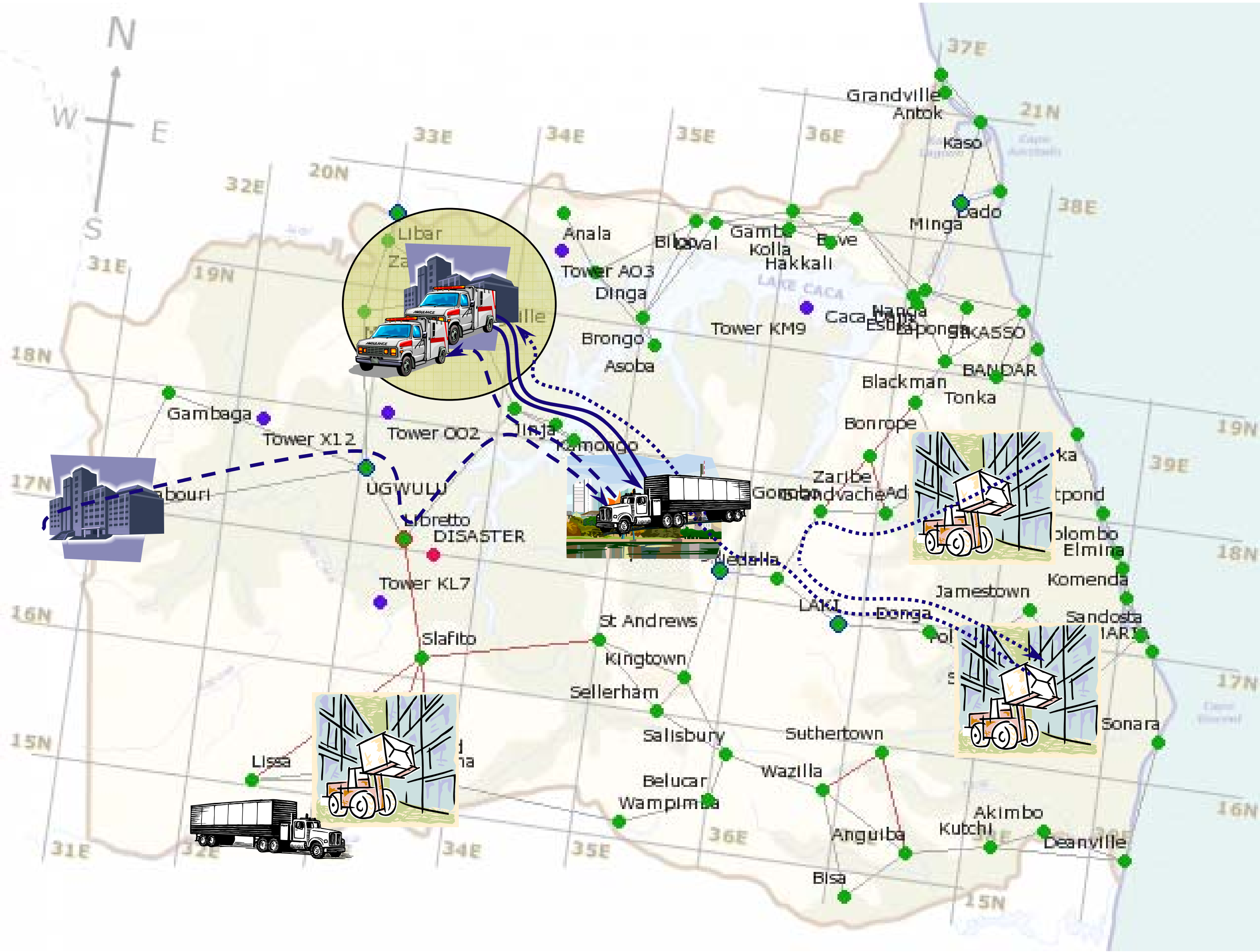


Case Study: Scenario



Context-Driven Methodology: Major Approach Ideas (1/2)

- Proposed approach was based on
  - *Ontology management* to provide for semantic interoperability
  - *Context management* to provide for situation awareness
  - Two types of contexts are considered
    1. ***- abstract context*** defining the structure of the problem / situation,
    2. ***- operational context*** defining its parameters.
    - The operational context is built based on the abstract context and information obtained from sensors and other sources. It is constantly updated to provide up-to-date information for problem solving.
  - *Profiling based on decision mining* to provide for user-centric decision support

Context-Driven Methodology: Major Approach Ideas (2/2)

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- *Common shared Application Ontology (AO)* serves for terminology unification.
  - Each service has a fragment of this ontology corresponding to its capabilities / responsibilities. This fragment is synchronized automatically when necessary (not during the response operation).
- Each operation member is represented by a *profile* describing its capabilities.
- *Web-service* standards are used for interactions.
  - External sources (e.g., medical databases, transport availability sources, weather forecasts' sources) should also support these standards and the terminology defined by the AO. This is achieved by developing wrapping services for each particular source.
- Each service is assigned an *intelligent agent*, representing it (together they will be called "*agent-based service*").
  - The agent collects information required for situational understanding by the service and *negotiates* with other agents to create ad-hoc action plans.
  - The agent has predefined rules to be followed during the negotiation processes. These rules depend on the role of the appropriate member.

Context-Driven Methodology: Levels of Integration of Knowledge & Information

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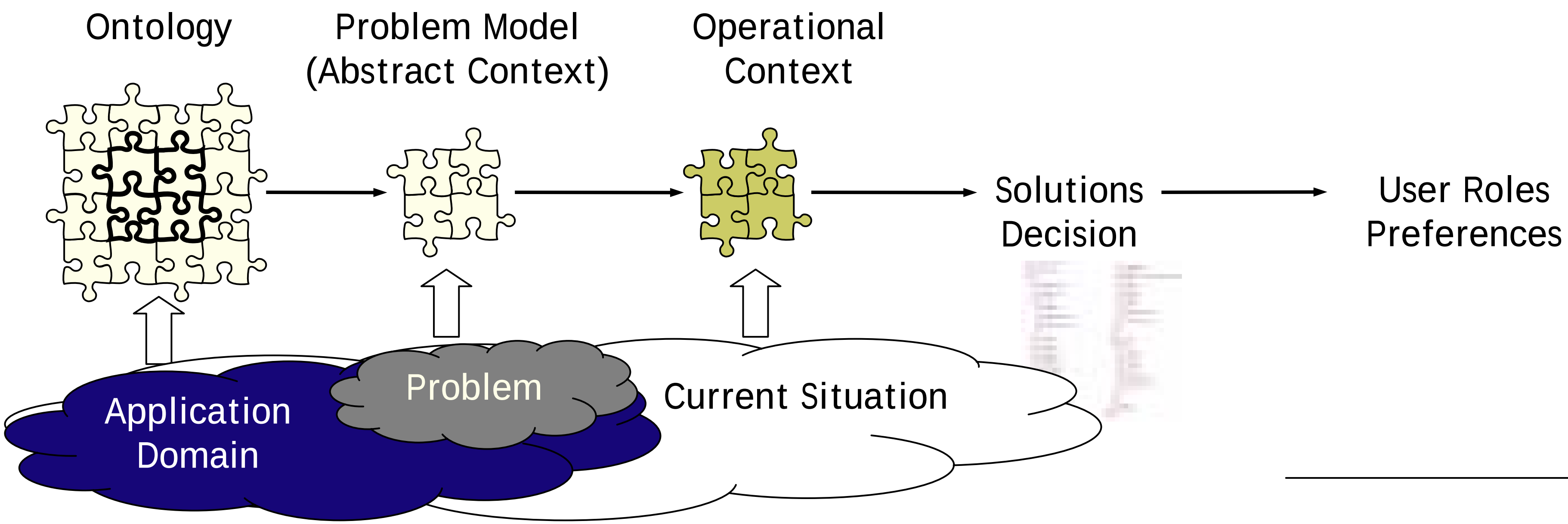
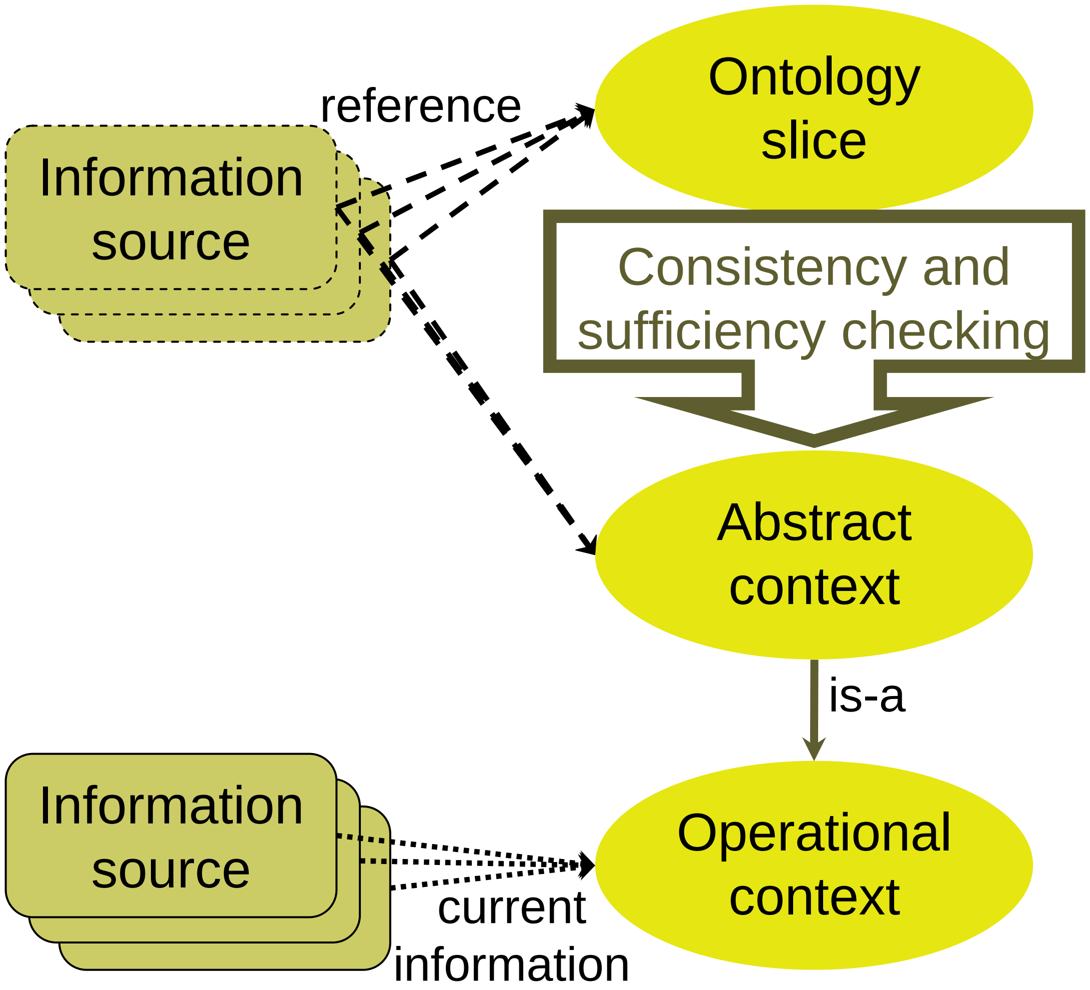
- **Domain level**
  - Integration of heterogeneous knowledge describing the domain knowledge
- **Task level**
  - Integration and formalization of tasks and problem-solving methods
- **Context level**
  - Integration of information and knowledge relevant to the problem or situation
- **Decision level**
  - Comparison of decisions & solutions by user roles



Context-Driven Methodology: Problem Modelling



Information & knowledge relevant to the user problem

Ontology-based problem model *(a model of macro situation)*

Instantiation of the abstract context with data values provided by information sources (*a situation model along with changeable data*)

Context-Driven Methodology: Common Knowledge Representation Model (1/2)

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Ontology	Object-oriented constraint network (OOCN)	Constraint satisfaction problem
Class	**Object (class)**	**Variable**
Attribute	**Variable**	
Attribute domain	**Variable domain**	**Variable domain**
Relationships	**Constraints**	**Constraints**
O = <C, A, D, R> C **– a set of classes,** A **– a set of class attributes,** D **– a set of attribute domains,** R **– a set of relationships**	OOCN = <O, V, D, C> O **– a set of objects,** V **– a set of object variables,** D **– a set of variable domains,** C **– a set of constraints**	CSP = <V, D, C> V **– a set of variables,** D **– a set of variable domains,** C **– a set of constraints**

Context-Driven Methodology: Common Knowledge Representation Model (2/2)

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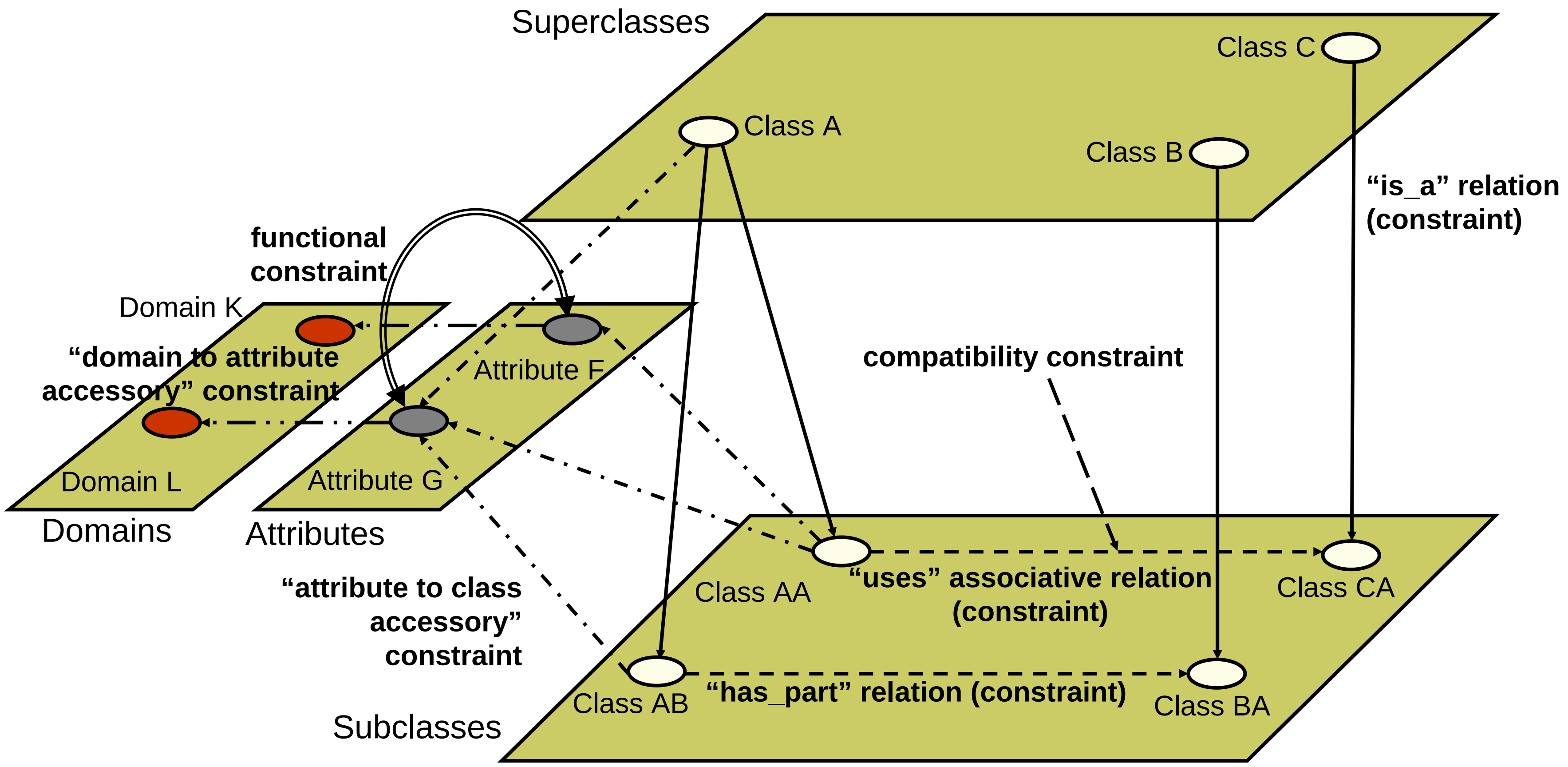

Context-Driven Methodology: Examples of Constraints

- *Class*, *Attribute*, *Domain*: (Weather, Air Temperature, Float);
- *IS-A*: (Disaster Relief, Weather Conditions);
- *PART-OF*: (Weather Conditions, Get Temperature);
- *Functional* constraint: F_1((Weather, Air Temperature), (Disaster Relief, Get Temperature));
- *Associative constraint*: (Disaster Event, Emergency Worker)
- *Class cardinality*: (Fire Department, Firefighter, 50)

Context-Driven Methodology: Example of OOCN for Determination of Road Availability

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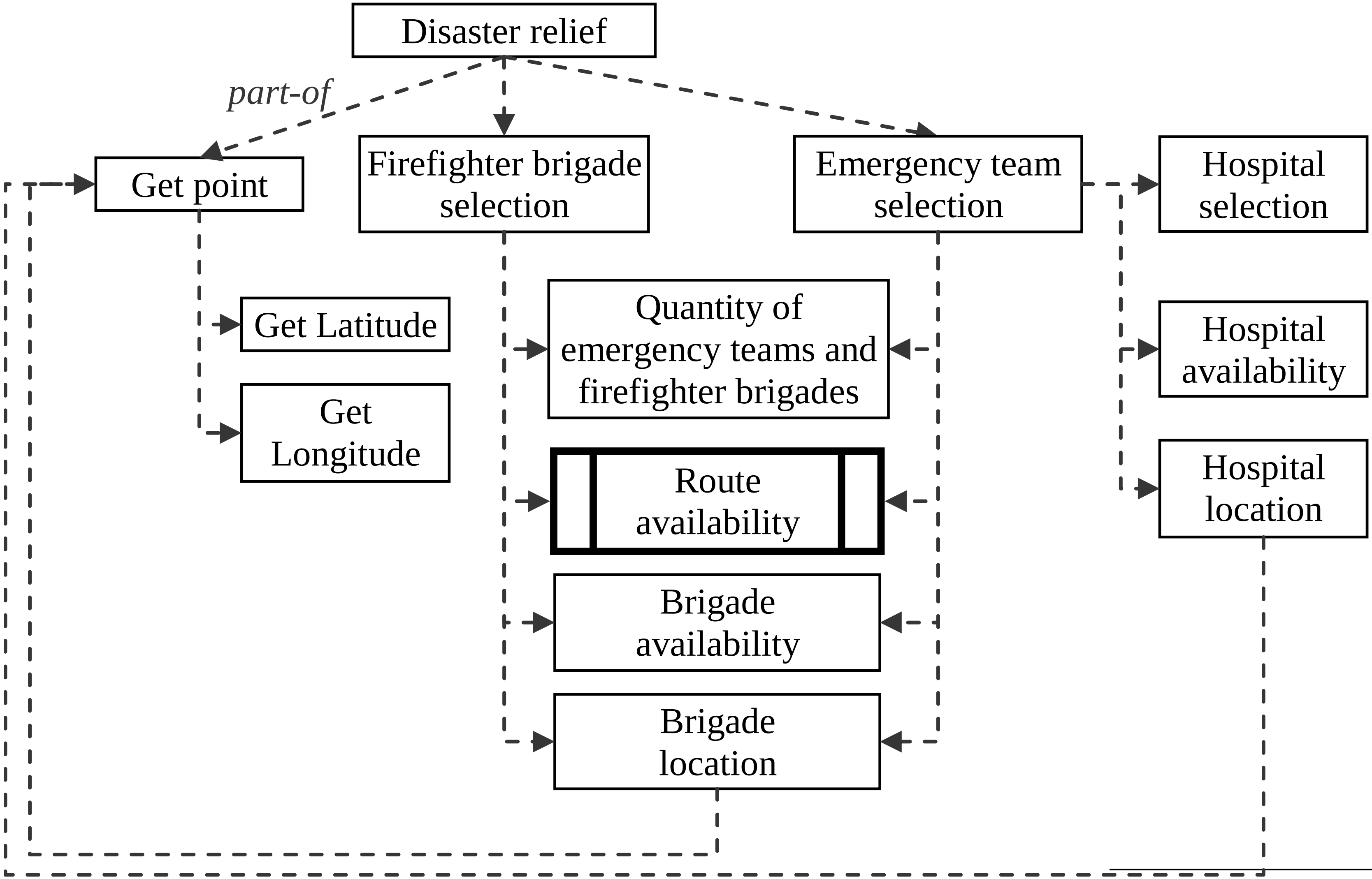
- v11 ∈ V: [Road].[available]; d11 ∈ D: [Road].[available] ∈ {True, False};
  c11∈C: [Road].[available]=True, c12∈C: [Road].[available]=*Route availability*([Road].[flooded]);
- v21 ∈ V: [Road].[flooded]; d21 ∈ D: [Road].[flooded] ∈ {True, False};
  c21 ∈ C: [Road].[flooded] = *Road floodability* ([Road].[floodable], [Weather].[precipitation]);
- v31 ∈ V: [Road].[floodable]; d31 ∈ D: [Road].[floodable] ∈ {True, False};
- v41 ∈ V: [Weather].[precipitation]; d41 ∈ D: [Weather].[precipitation] ∈ (0, 100);
  c41 ∈ C: [Weather].[precipitation] = *Get Precipitation* ();

Context-Driven Methodology: Application Ontology (Class View for Task Constituent)



Context-Driven Methodology: Simon's Model and Proposed Approach

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Simon's phase names	Intelligence	Design	Choice
Phase content	Problem recognition	Alternatives generation	Efficient alternatives selection
Steps	• fixing goals • setting goals	• designing alternatives	• evaluation & choosing alternatives
Proposed approach steps	• **abstract context composition** • **operational context producing**	• **constraint-based generating efficient alternatives**	

Technological Foundations:
Hybrid Technology for Decision Making

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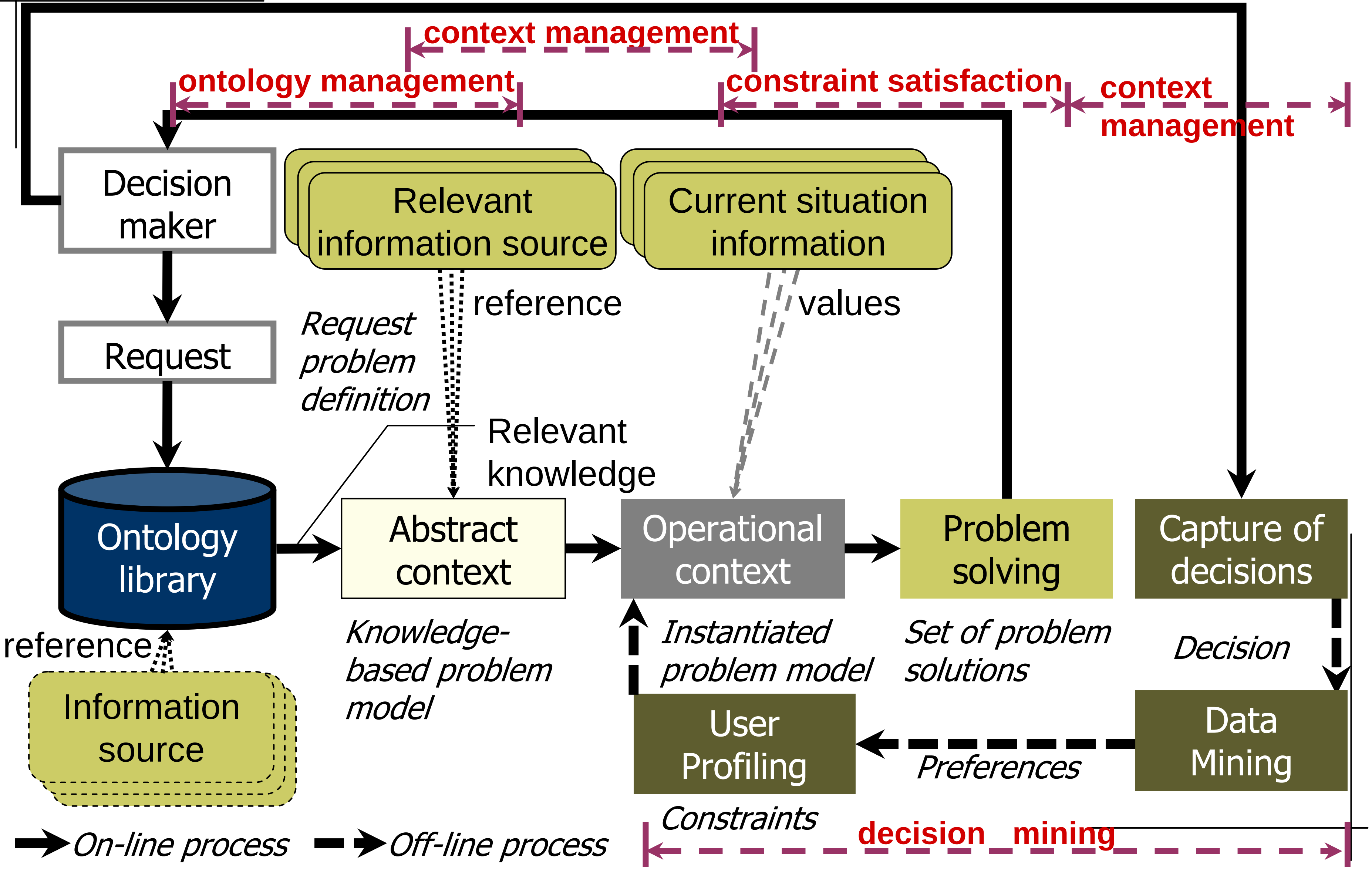

Technological Foundations: Framework (1/2)

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Objectives in the theoretical foundations	Techniques	Technology	Result in terms of OOCN
Application ontology building	Ontology building from scratch, integration of existing ontologies	Ontology engineering, ontology management	OOCN with non-instantiated variables
Resource representation	Web-service profile	Semantic Web-services	OOCN with non-instantiated variables
Overcoming Web-services heterogeneity	Alignment of ontology and service descriptions	Semantic service profile matching	OOCN with associative (alignment) constraints
Abstract context creation	Ontology slicing	Ontology management	General problem model
Determination of contextual resources	Ontology slicing	Ontology management	OOCN with associative (alignment) constraints
Operational context producing	Service communications	Web-service composition, context management	OOCN with fully instantiated variables

Technological Foundations: Framework (2/2)

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Objectives in the theoretical foundations	Techniques	Technology	Result in terms of OOCN
Generation of alternative action plans	Solving of constraint satisfaction problem	Constraint satisfaction	A set of feasible solutions
Choice of a specific plan	Optimization	Constraint programming	An efficient solution
Plan implementation	Service communications	Mobile applications, collective decision making	The efficient solution
Context reusability	Context archiving	Context management	OOCN with partly instantiated variables
Revealing user preferences	Context-based decision archiving	Profiling, decision mining	A set of user constraints
DSS implementation	Service-oriented architecture	Web-services Smart space Web-based community	

Technological Foundations: Service-oriented Architecture of DSS

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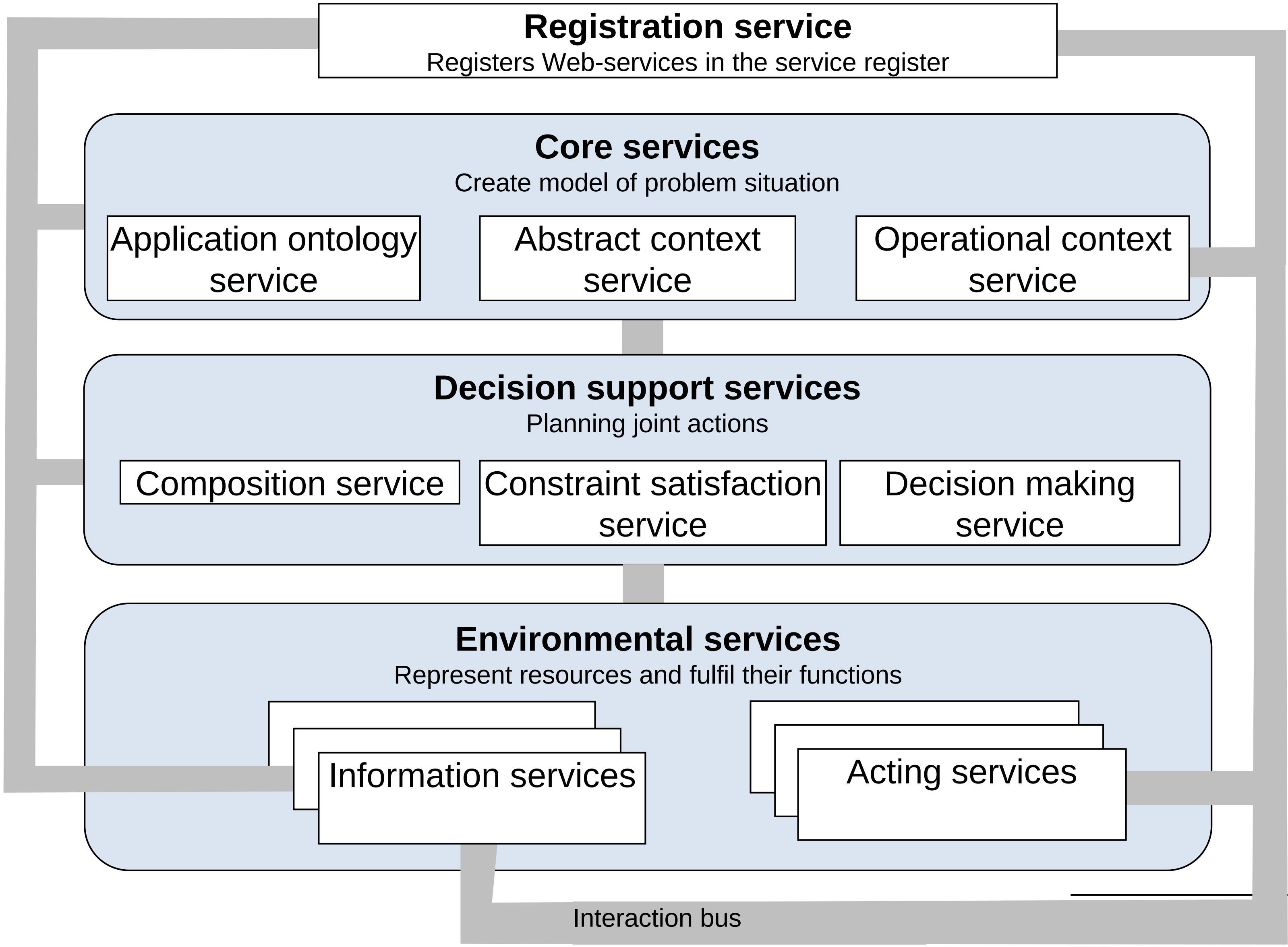
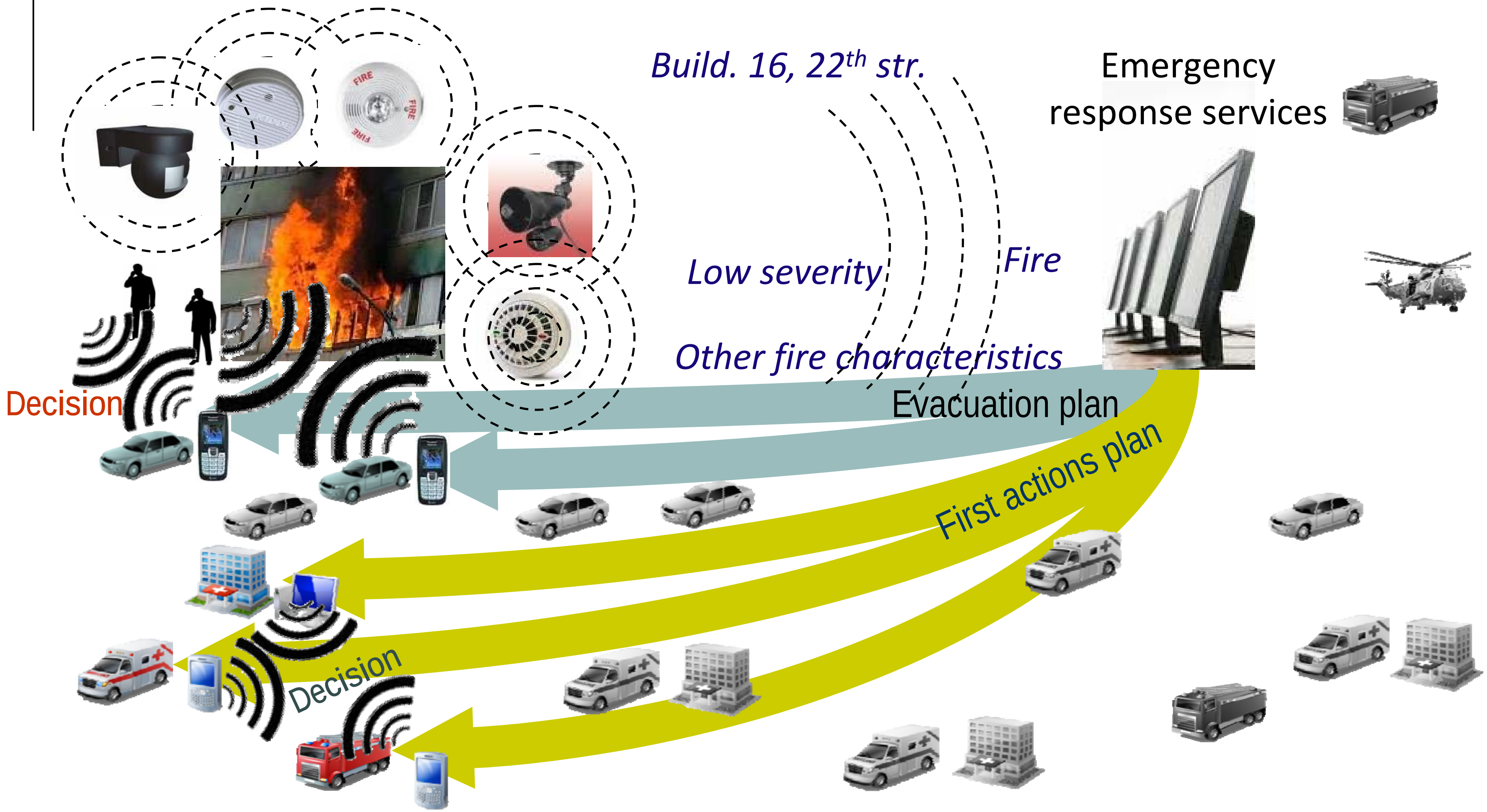


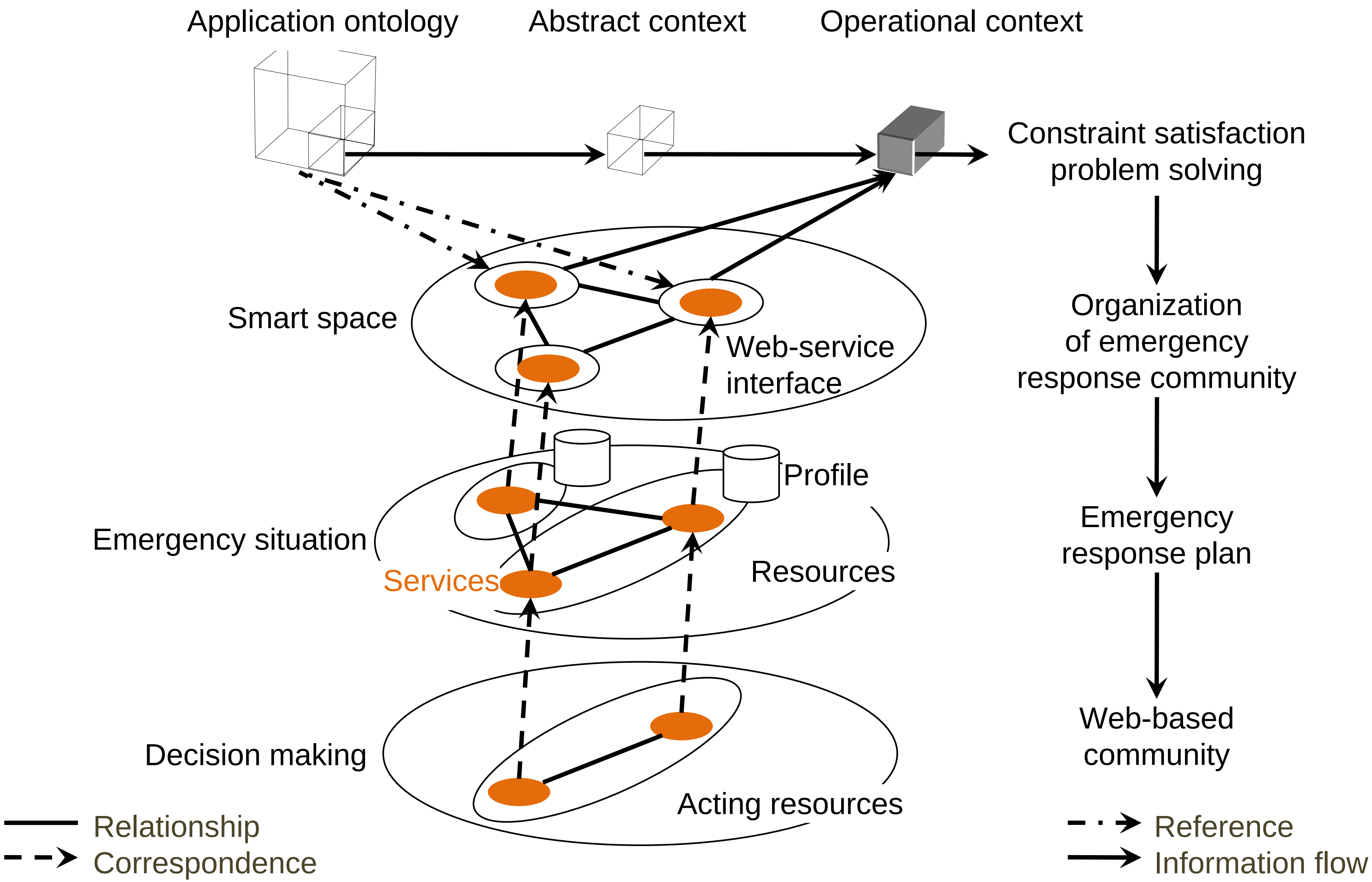
Case Study: Fire Response

Scenario



Case Study: Fire Response

Technological Framework



Case Study: Fire Response

Service-Oriented Architecture

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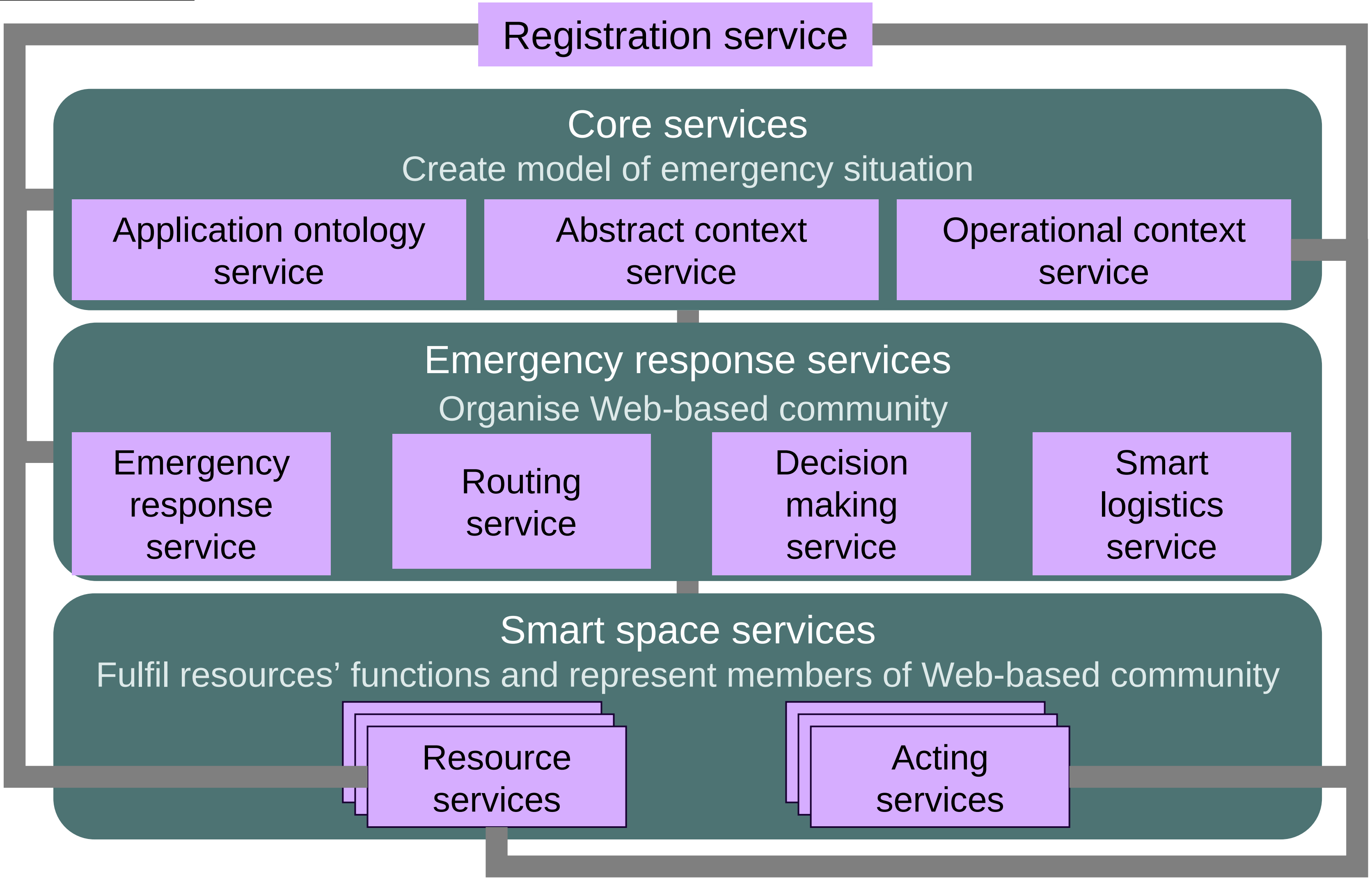

Case Study: Fire Response

Plan for First Response Actions

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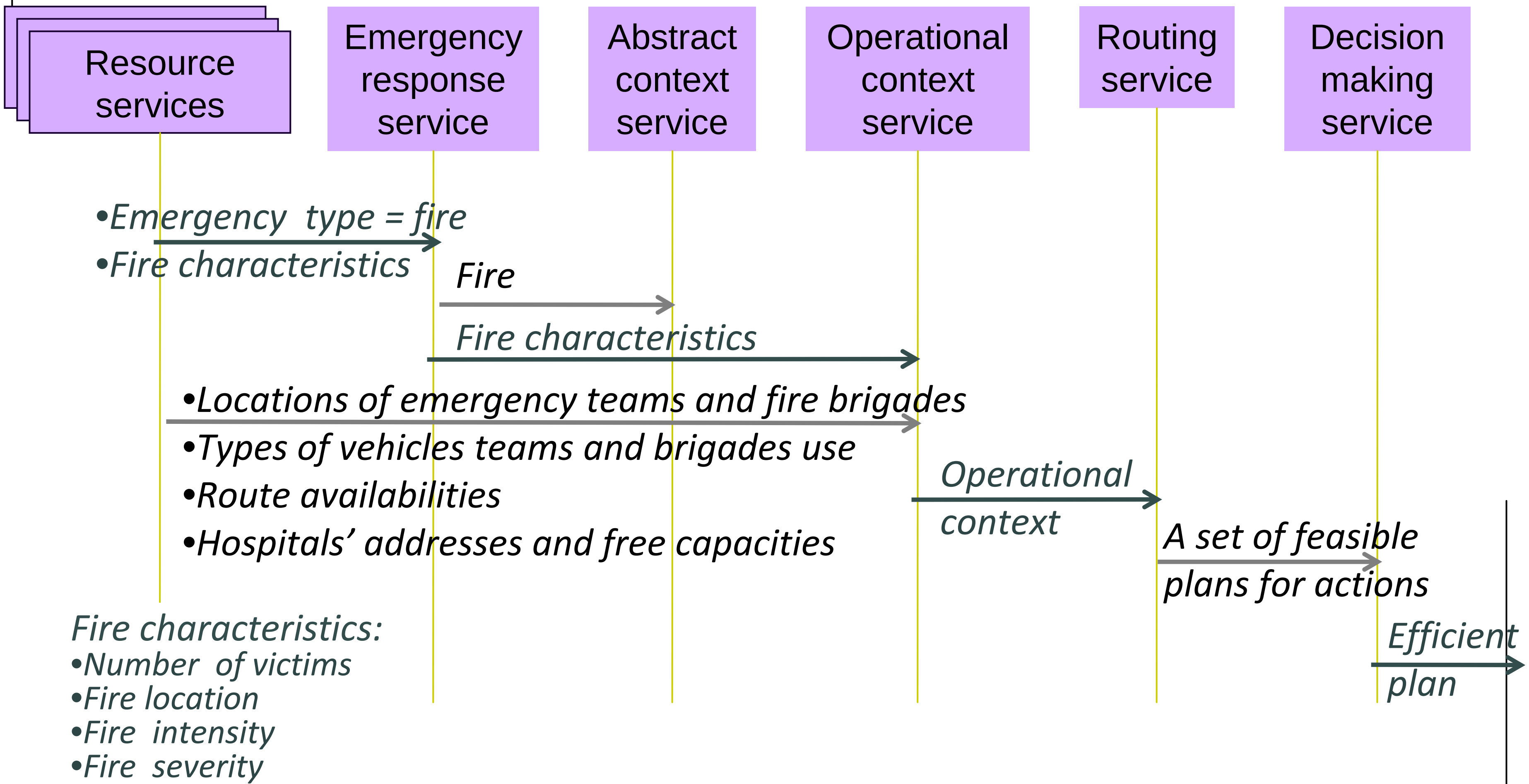
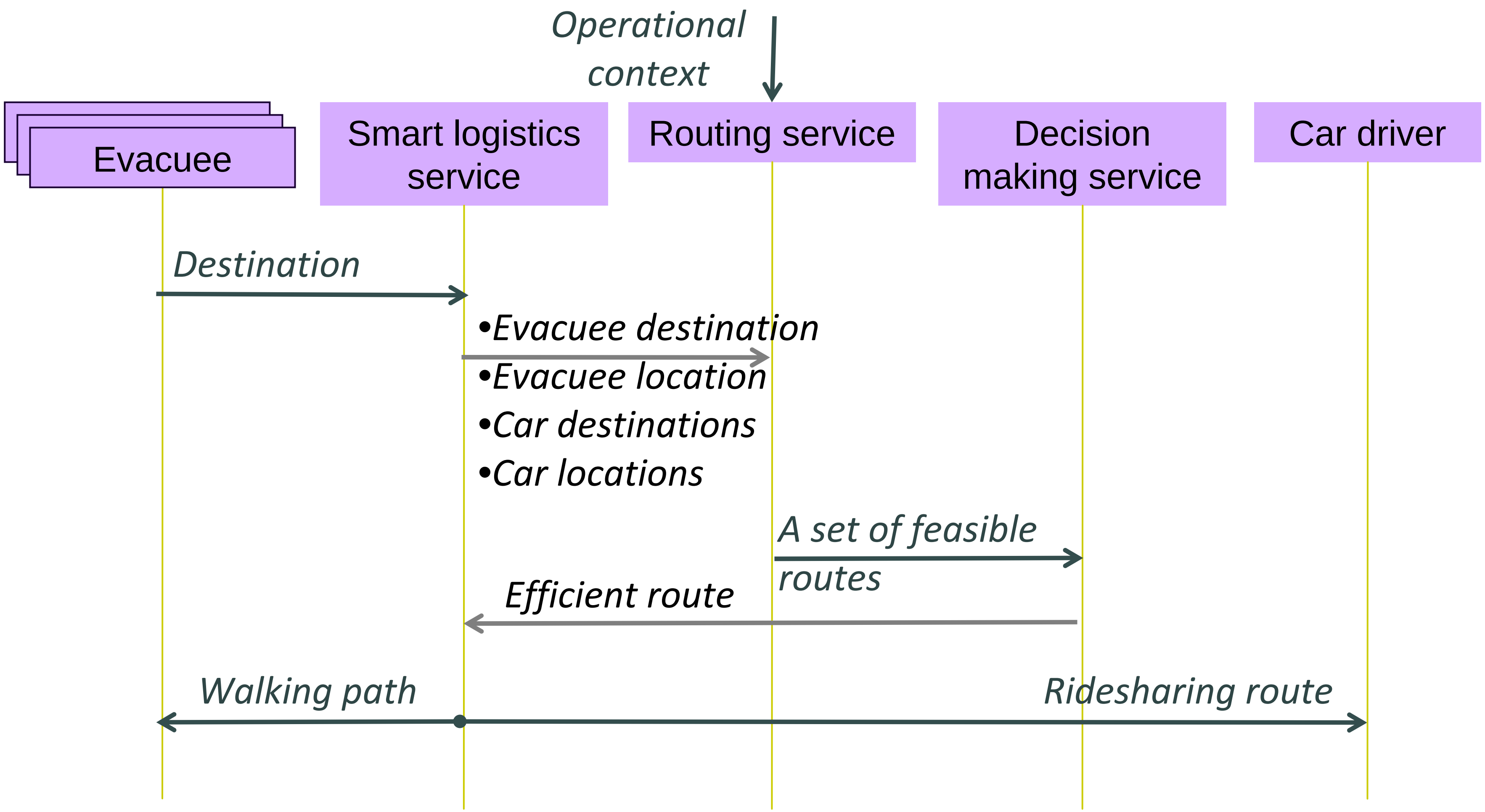


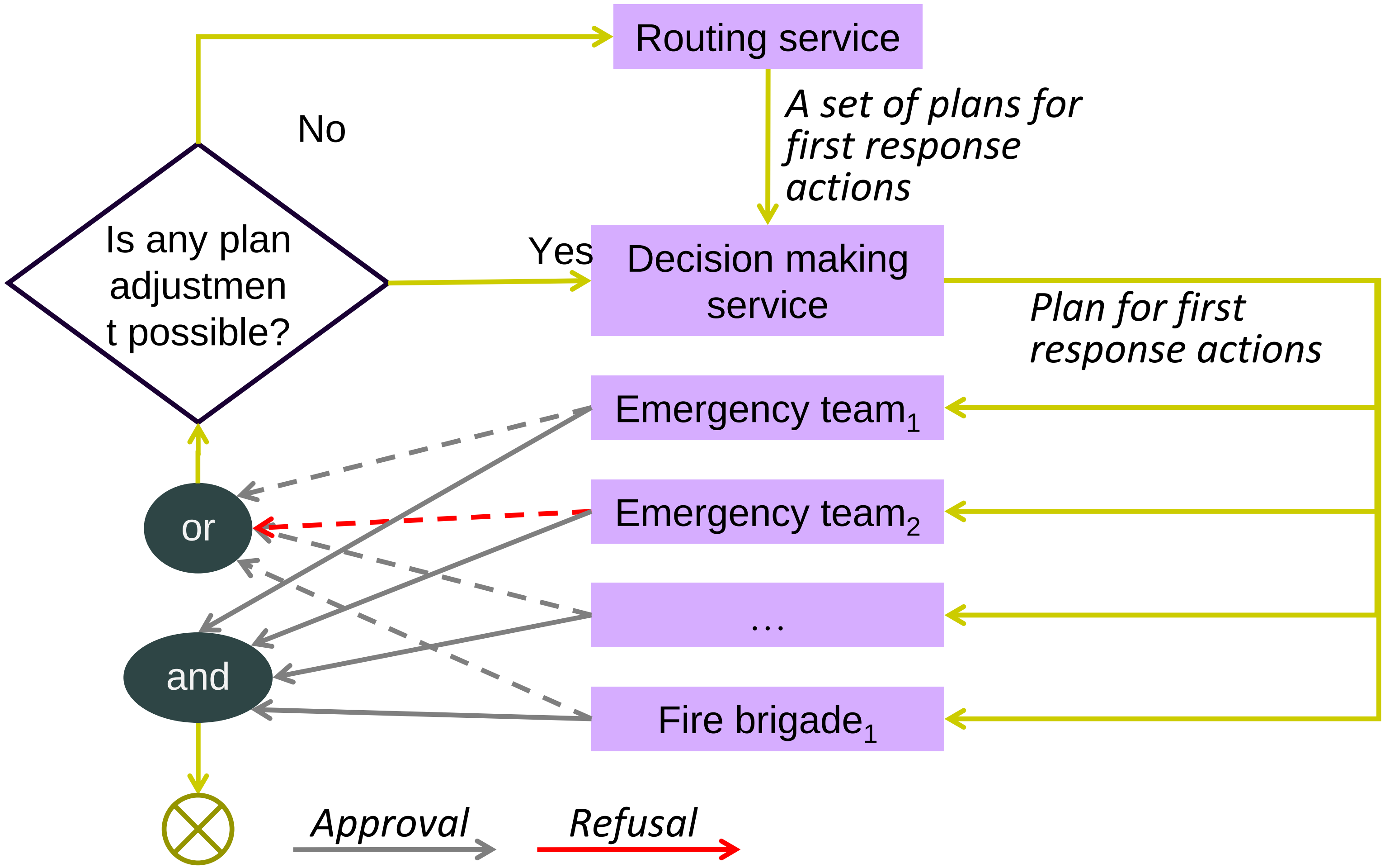
Case Study: Fire Response

Evacuation Plan



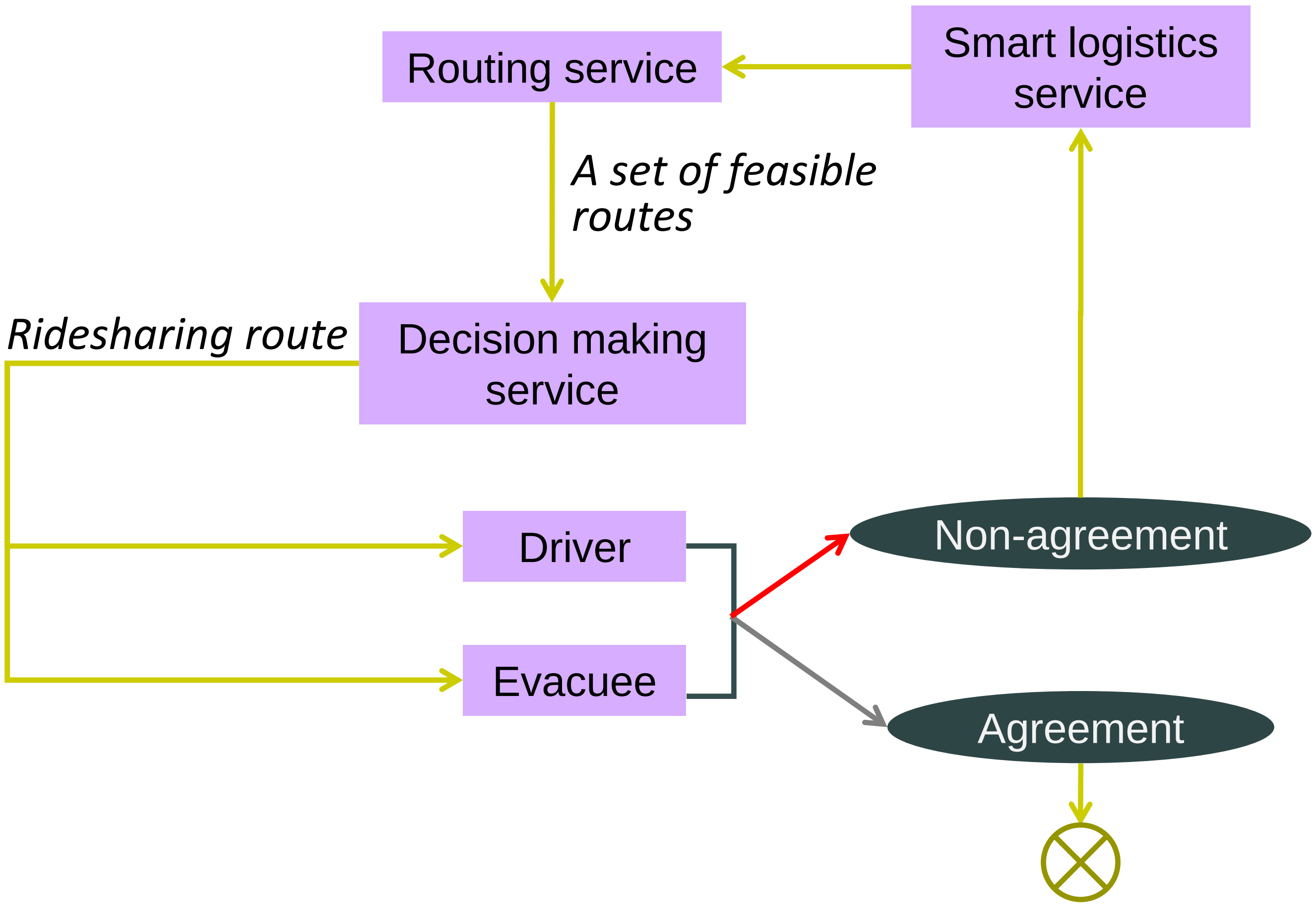
Case Study: Fire Response

First Response Actions



Case Study: Fire Response

Evacuation



Case Study: Fire Response

Application ontology

- Emergency management
  - 7 taxonomy levels
  - More than 600 classes
  - More than 160 class attributes
  - More than 40 hierarchical relationships
  - More than 50 associative relationships
  - More than 30 functional constraints

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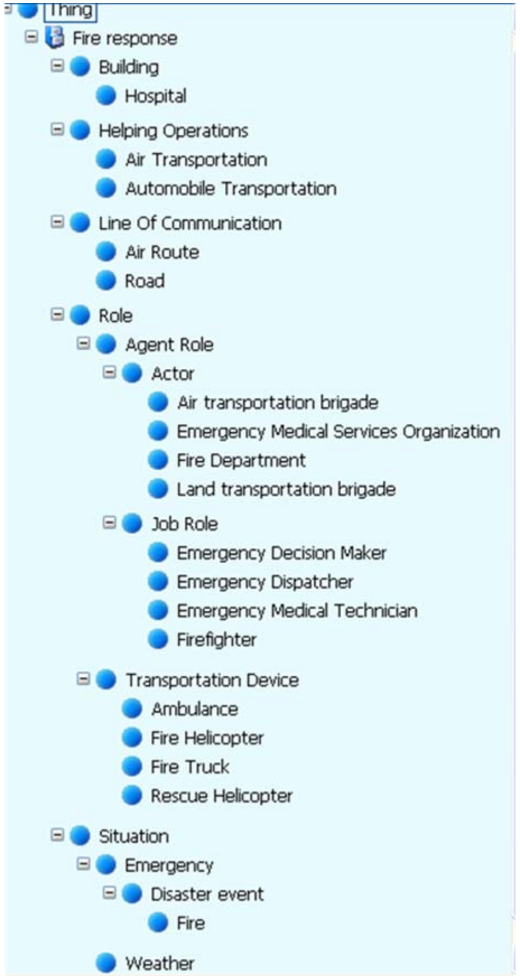
Case Study: Fire Response

Abstract context



- 3 taxonomy levels
- 17 bottom-level classes
- 38 class attributes
- around 30 relationships of different types

Case Study: Fire Response

Acting Resources

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- Ambulances
- Fire brigades
- Car driver

Attributes to be instantiated

- Locations
- Availabilities
- Capacities
- Facilities

Case Study: Fire Response

Operational context

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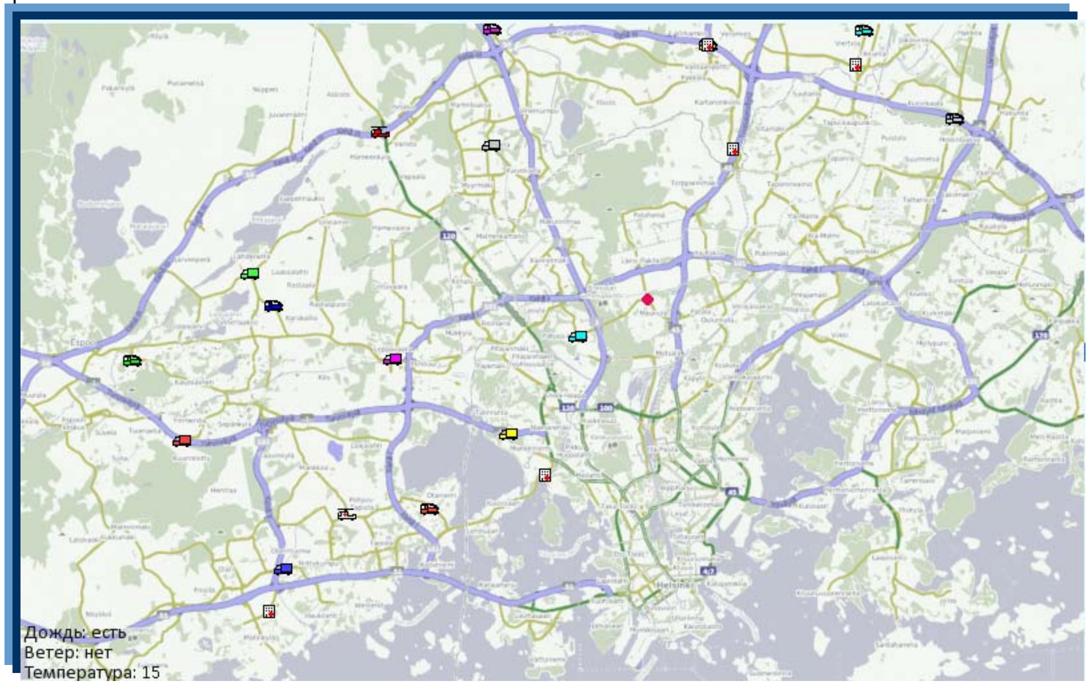


- 9 victims
- 6 fire brigades in 6 fire trucks
- 1 fire brigades in a fire helicopter
- 7 emergency teams in 7 ambulances
- 1 emergency teams in a rescue helicopter
- 5 hospitals having free capacities for 4, 4, 2, 3, and 3 patients

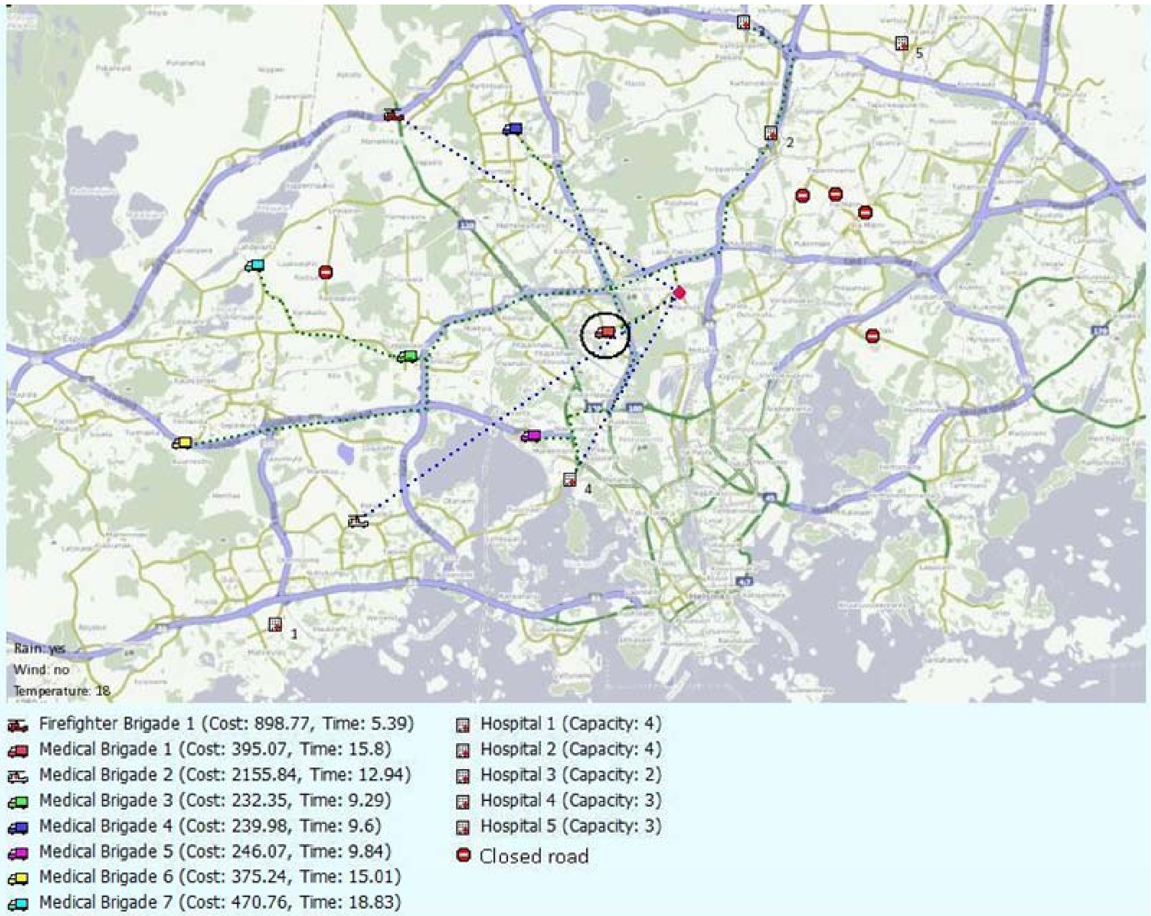
Case Study: Fire Response

Plan Components

- Acting resources
  - Emergency teams
  - Fire brigades
  - Car drivers
- Transportation routes
  - Ambulances
  - Fire trucks
  - Cars
- Helping services
  - Hospitals

Case Study: Fire Response

Plan on First Response Actions



- Efficiency criteria
  - minimal time of arrival of fire brigade at the fire location
  - minimal time of victim transportations
- Acting resources
  - 1 fire helicopter
  - 6 ambulances (1 ambulance (encircled in the figure) going from the fire location to the hospital twice)
  - 1 rescue helicopter (going from the fire location to the hospital twice)
  - hospitals having free capacities for 4, 2, and 3 patients
- Estimated time needed for transportations of 9 victims to hospitals
  - 1 h. 25 min.

Case Study: Fire Response

Prototype Description

- The prototype is a distributed Web-based system
- In can be accessed through any Internet browsers from a notebook, PDA, mobile phone, *etc*.
  - the Internet today can be accessed from almost everywhere via, for example, a satellite).
- The decisions are delivered to the leaders of the emergency and rescue teams, and to the hospital administrations.

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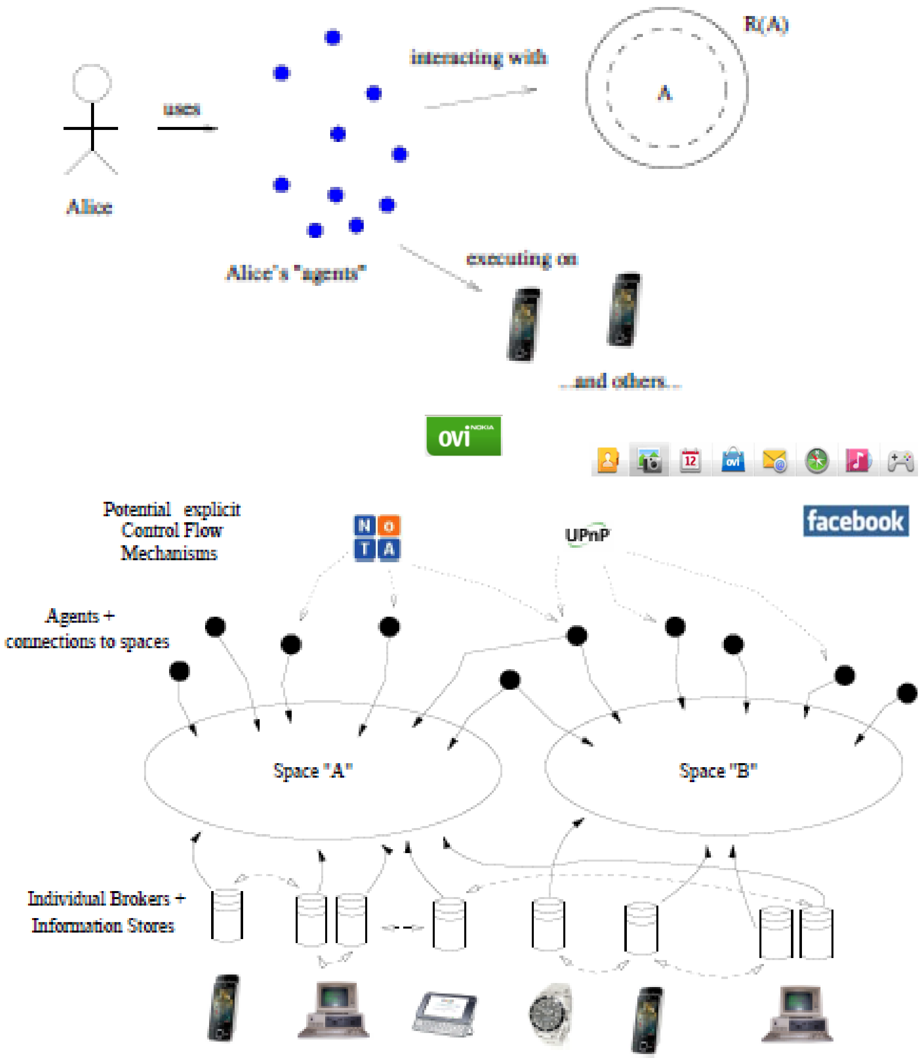
Case Study: Fire Response

M3 Smart Space (1/2)



Space-based Computing Environment

- RDF/Triple-Store based
  - semi-structured information
  - ontology agnostic

- multiple, individual autonomous spaces
  - information distribution over multiple devices
  - embedded, OVI, PC, Mobile, etc.

Resources:

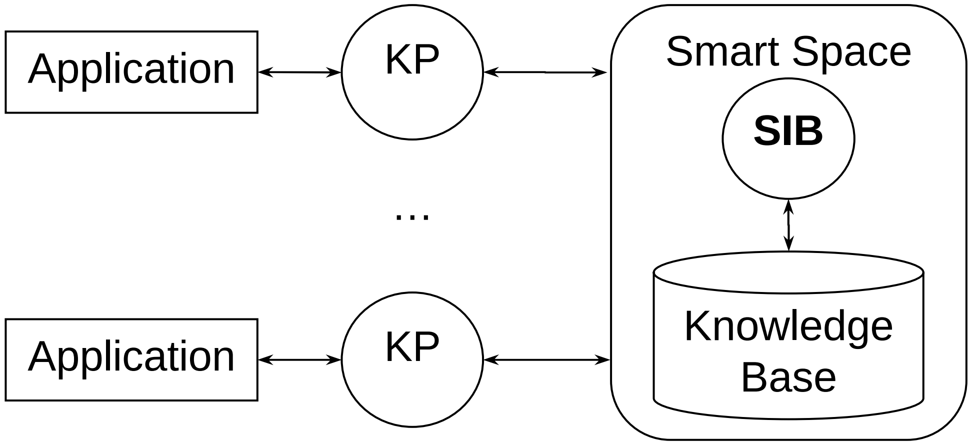
http://sourceforge.net/-projects/-smart-m3

http://en.wikipedia.org/wiki/Smart-M3

Case Study: Fire Response

M3 Smart Space (2/2)

- Devices and software entities (applications) can publish their embedded information for other devices and software entities through simple, shared Service Information Brokers (SIB) – a "push"-based information sharing model rather than specific publish-subscribe.
- The interface is provided by “***Knowledge Processors (KP)” (or Agents)***
- The understandability of information is based on the usage of the common RDF ontology models and common data formats.
- Smart-M3 is device, domain, and vendor independent.



SIB – Semantic Information Broker

Case Study: Fire Response

Access from Mobile Devices

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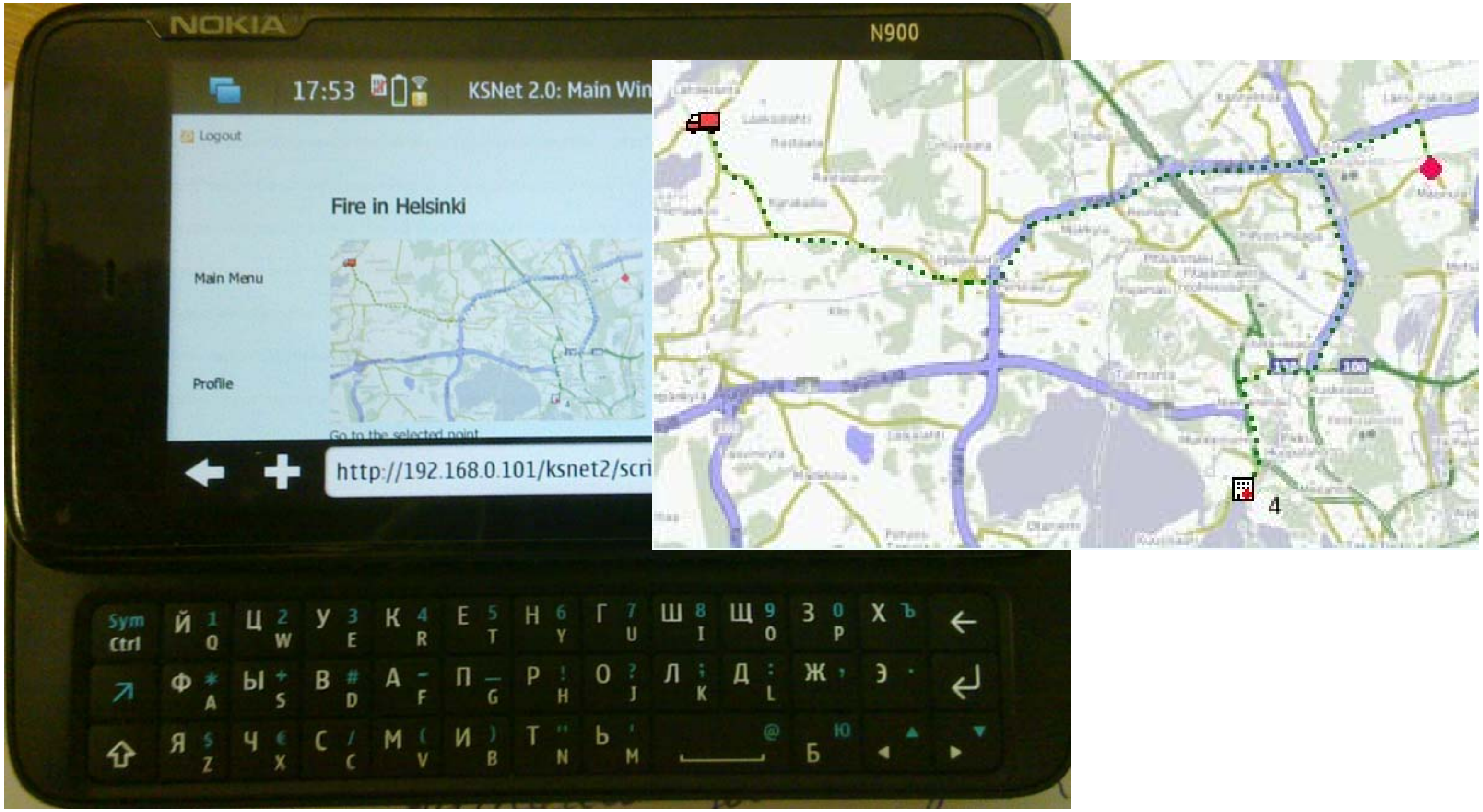
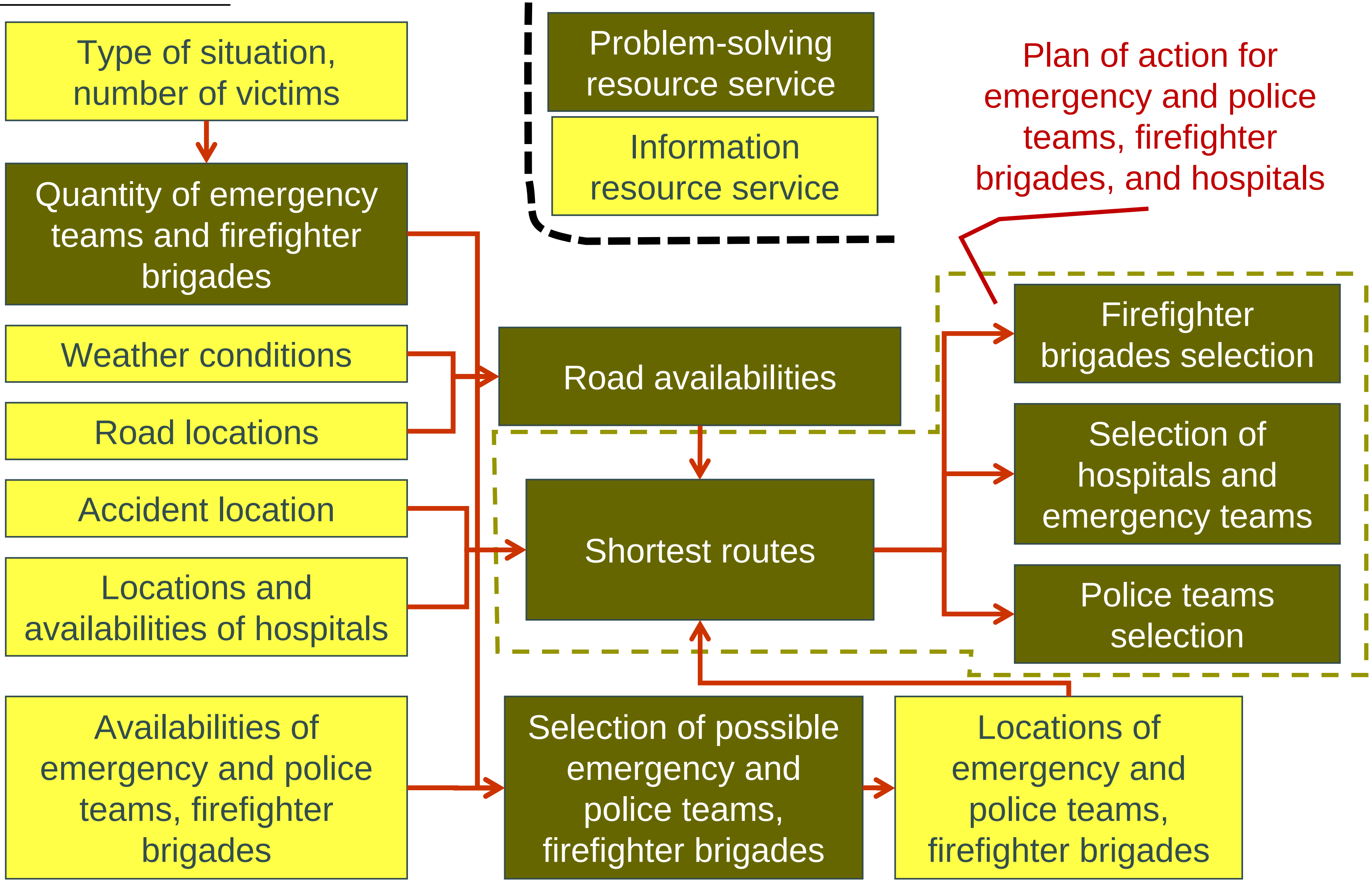


Plan for emergency team

Case Study: Fire Response

Composition of Web-Services



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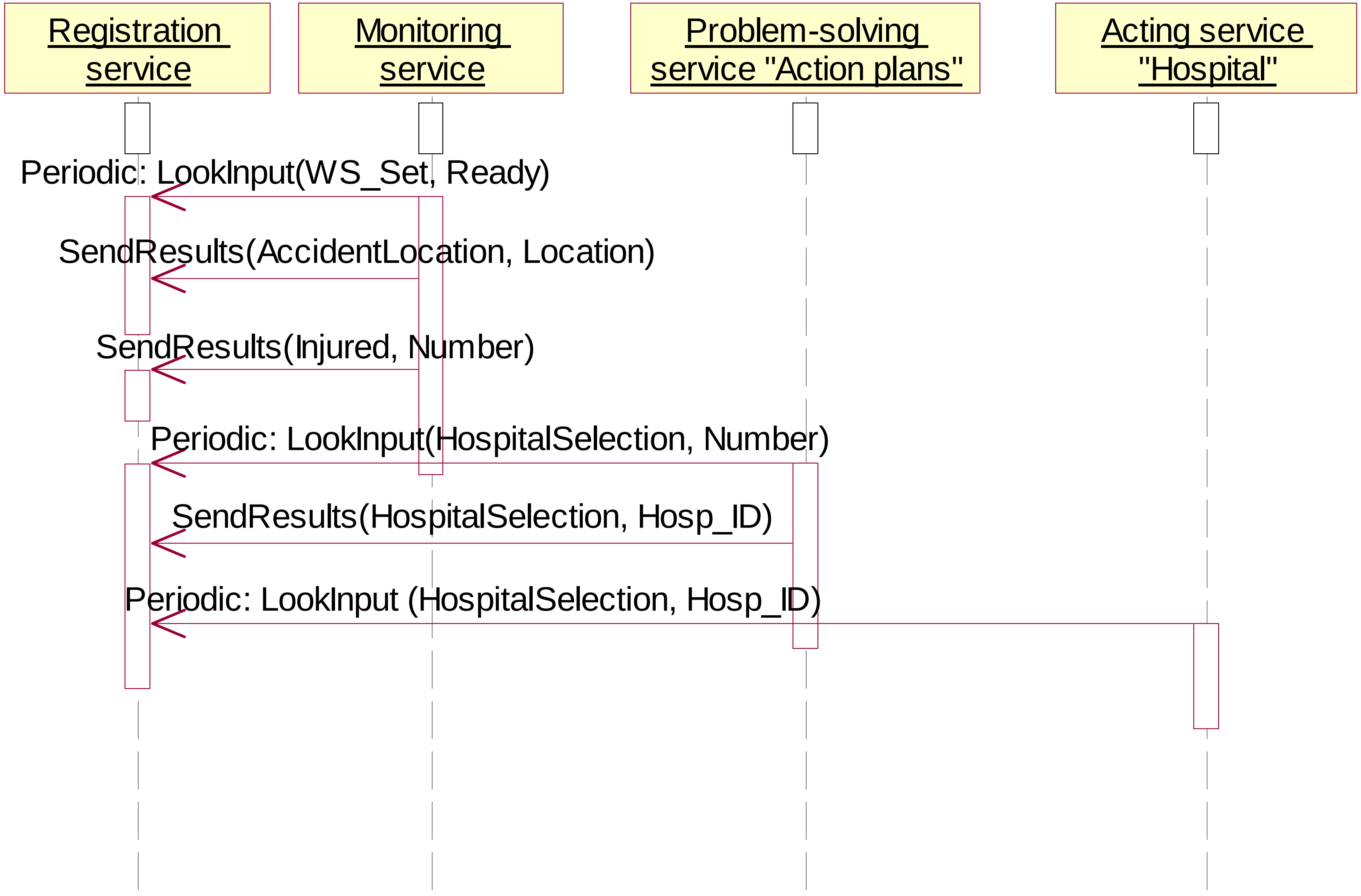
Web-Services’ Negotiations within the Web-based Community



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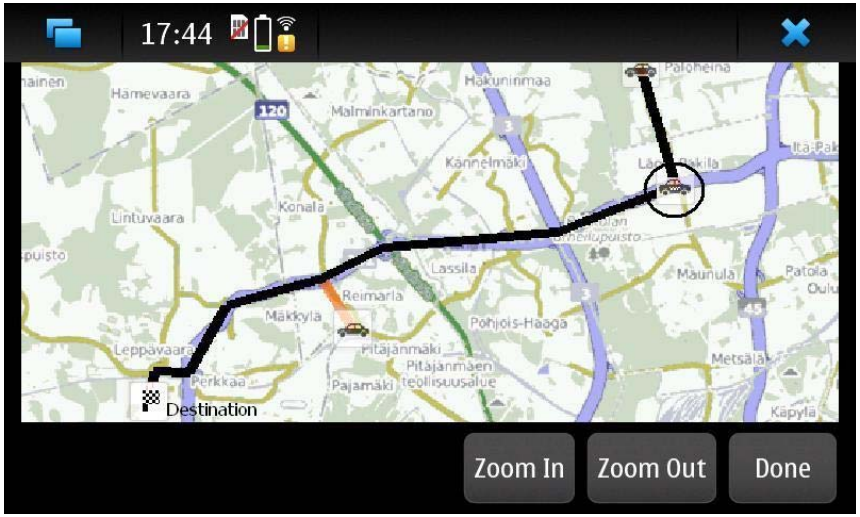
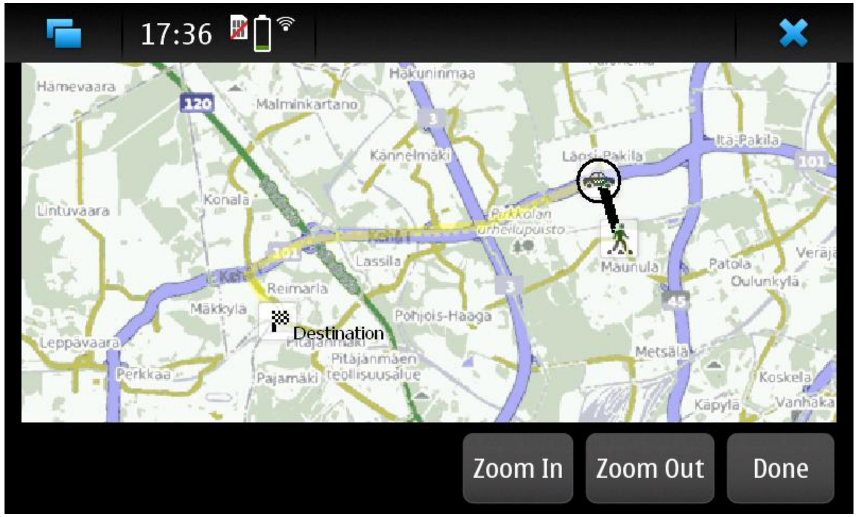
Evacuation Plan



Ridesharing route: driver's view



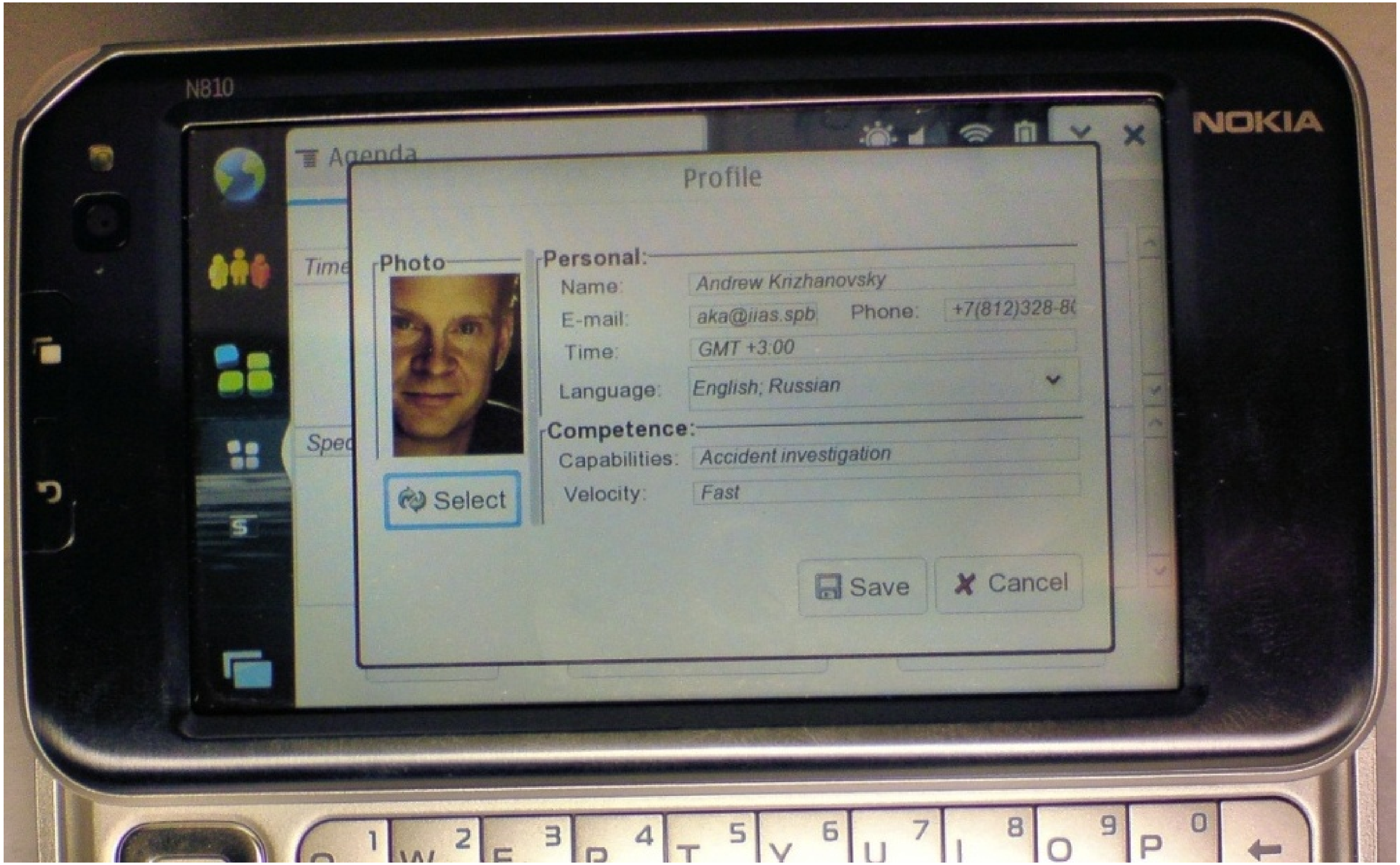
Ridesharing route: evacuee's view

- Evacuees
  - 26 persons to be evacuated
- Results
  - 22 persons evacuated by 16 cars

- Efficiency criteria
  - minimum evacuation time
  - maximum evacuation capacity

Case Study: Fire Response

Operation Member Profile



Case Study: e-Tourism

Individual Tourism

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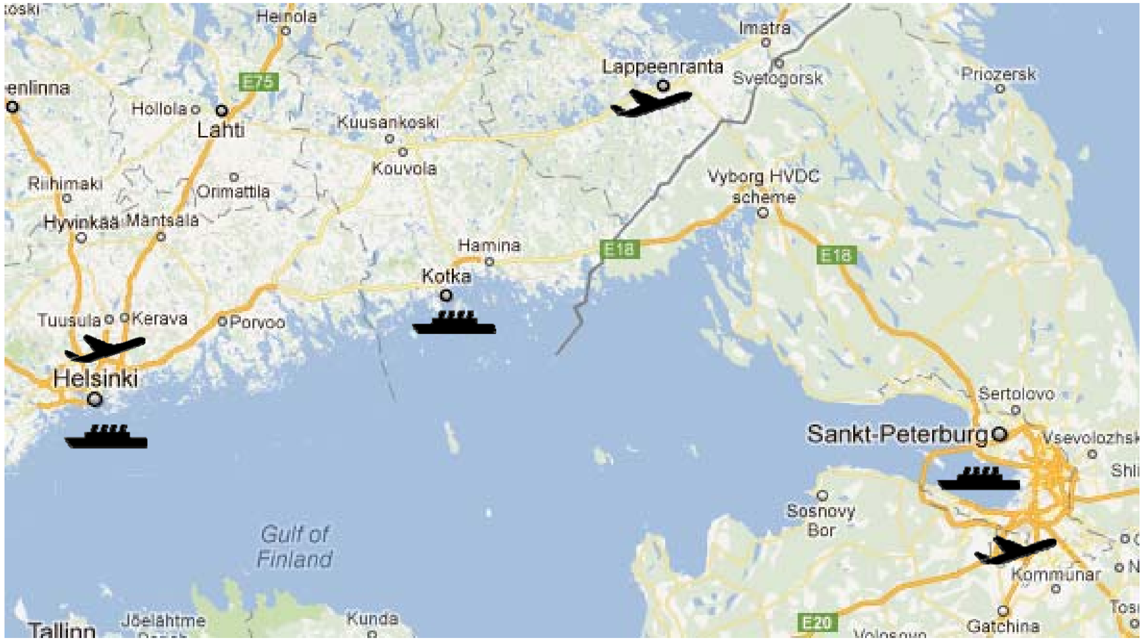
- Recently, the individual tourism has become more and more popular.
- Tourists are usually restricted in time but wish to see as many attractions as possible.
- Personal travel via cars, buses and trains is usually (and reasonably) done within the radius of 450-500 kilometers.

- The distance between St. Petersburg, Russia and Helsinki, Finland together with nearby cities (Imatra, Lappeenranta, Kotka, Vyborg) falls into this radius.

Case Study: e-Tourism

Region as a Transportation Hub

- The region between of St. Petersburg, Russia and Helsinki, Finland together with nearby cities (Imatra, Lappeenranta, Kotka, Vyborg) could constitute a universal hub for travelling all around the world



- It has airports (Helsinki, Lappeenranta, and St. Petersburg), ferries (Helsinki, Kotka, and St. Petersburg), trains, buses, automobile road network.
- This approach is a step to "infomobility" infrastructure
  - operation and service provision schemes when dynamic multi-modal information is delivered to the users, both pre-trip and, more importantly, on-trip.

Case Study: e-Tourism

Problem to Be Solved

- Today traveling problems
  - unpredictable situation at border crossing,
  - unknown traffic condition on the roads,
  - unknown occupancy of attractions
  - isolation of train, bus, and airplane schedules as well as attractions' schedules and special events.
  - …
- The proposed approach is aimed at support of dynamic configuration of virtual multimodal logistics networks based on tourist requirements and preferences.
- The main idea is to develop models and methods that would enable ad-hoc configuration of resources for multimodal logistics.
  - based on dynamic optimization of the visiting route and transportation means
  - take into account user preferences together with unexpected and unexpressed needs (on the basis of the profiling technology).

Case Study: e-Tourism

Virtual Tourist Hub Concept

- The idea of virtual hub has already been mentioned in the literature (though it could have a different name, e.g., “e-Hub”), but it is still devoted very little attention in the research community.
- Generally, virtual tourist hub represents a virtual collaboration space for two types of members:
  - transportation providers (who actually moves the passengers or cargo),
  - attraction service providers,
  - service providers (who provides additional services, e.g., sea port, border crossing authorities, etc.).
- These providers can potentially collaborate in order to increase the efficiency of the logistic network, however, it is not always the case.

Case Study: e-Tourism

Reference Model

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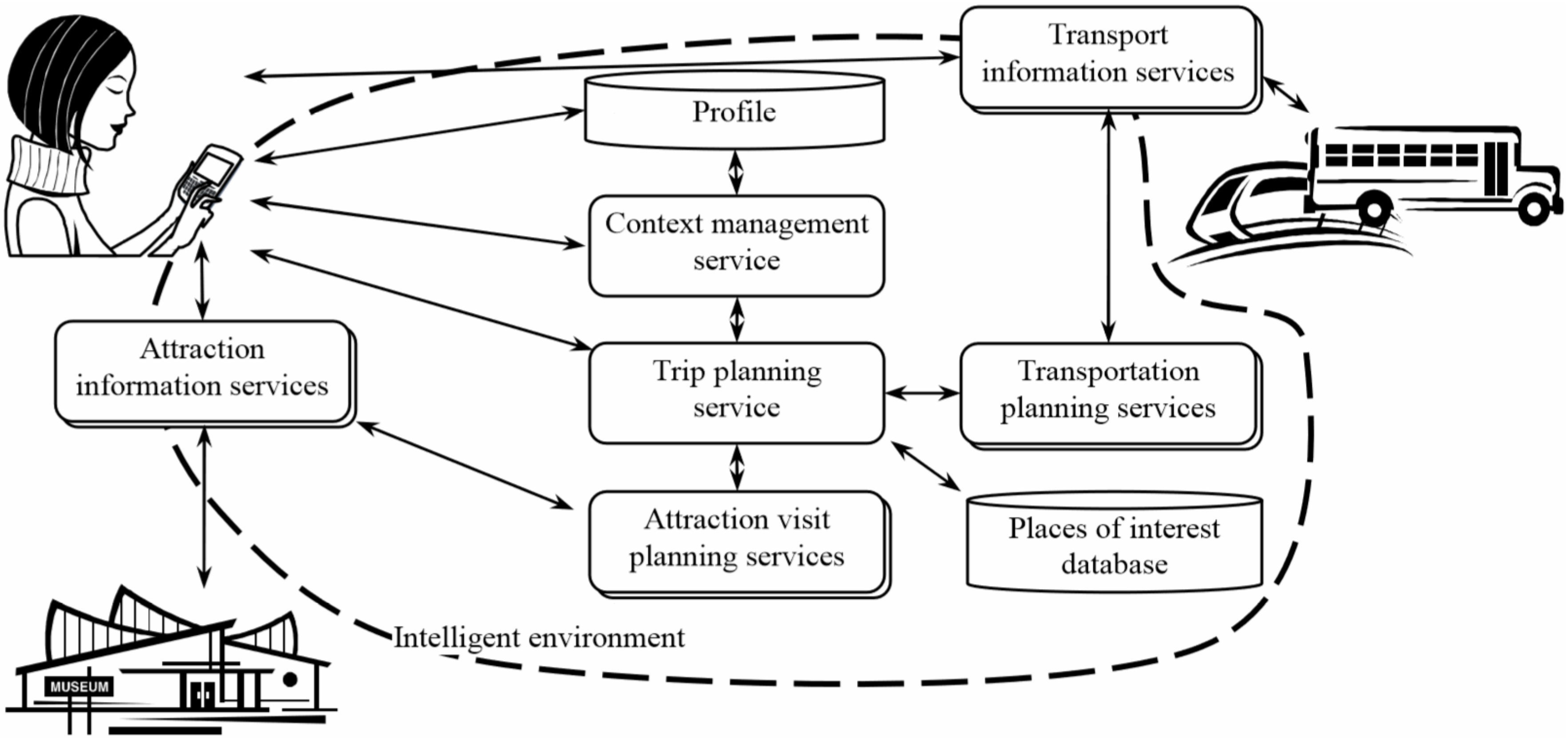

Case Study: e-Tourism

Attraction Information for Tourist

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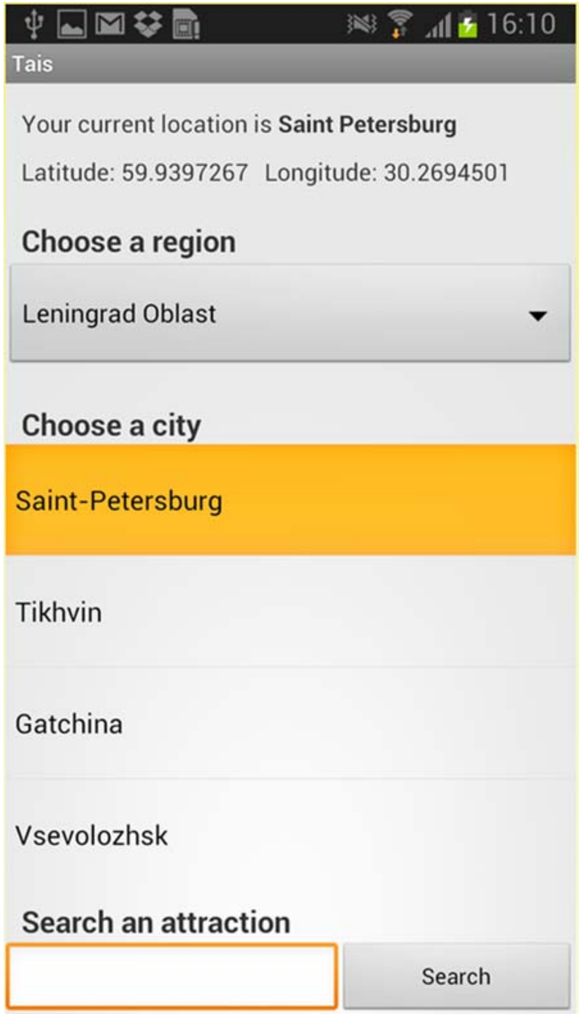

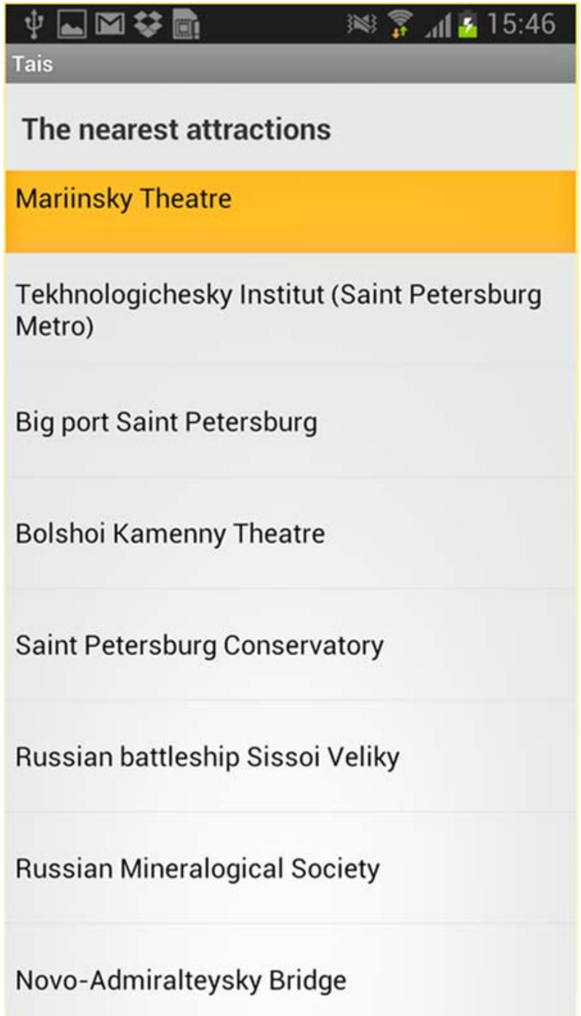

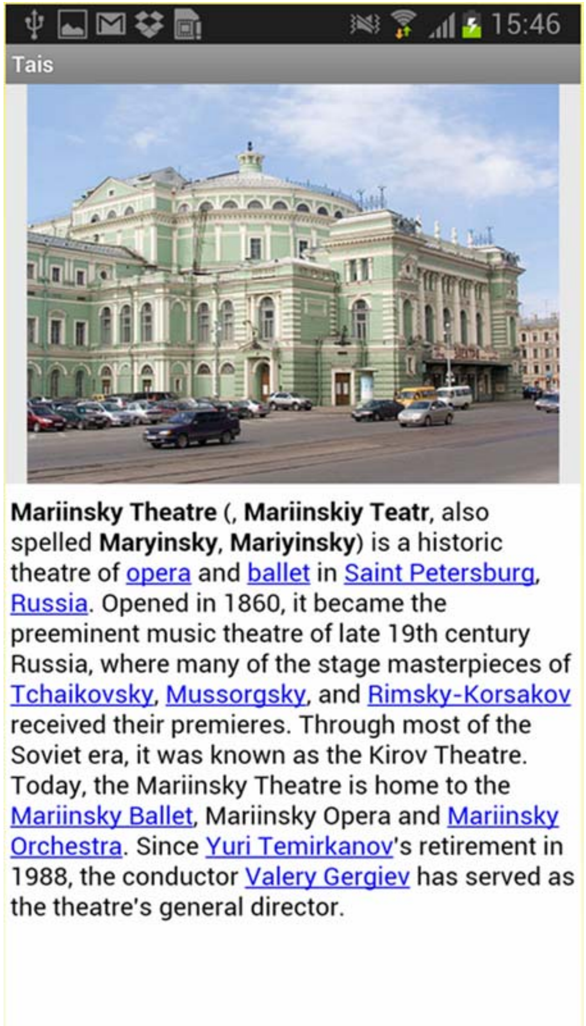

Case Study: e-Tourism

Attraction Information Retrieval

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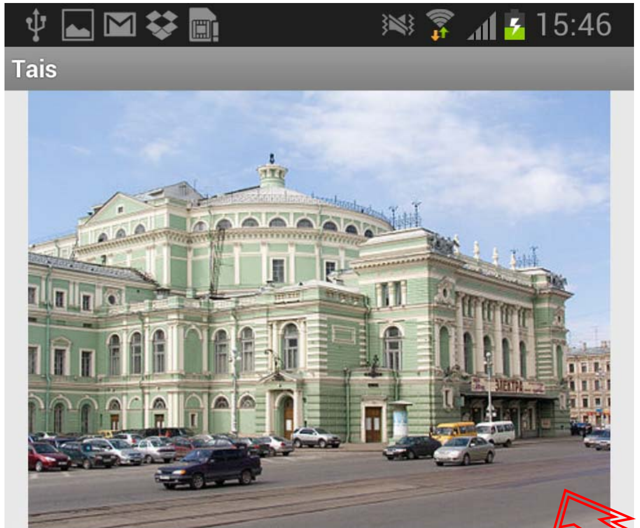
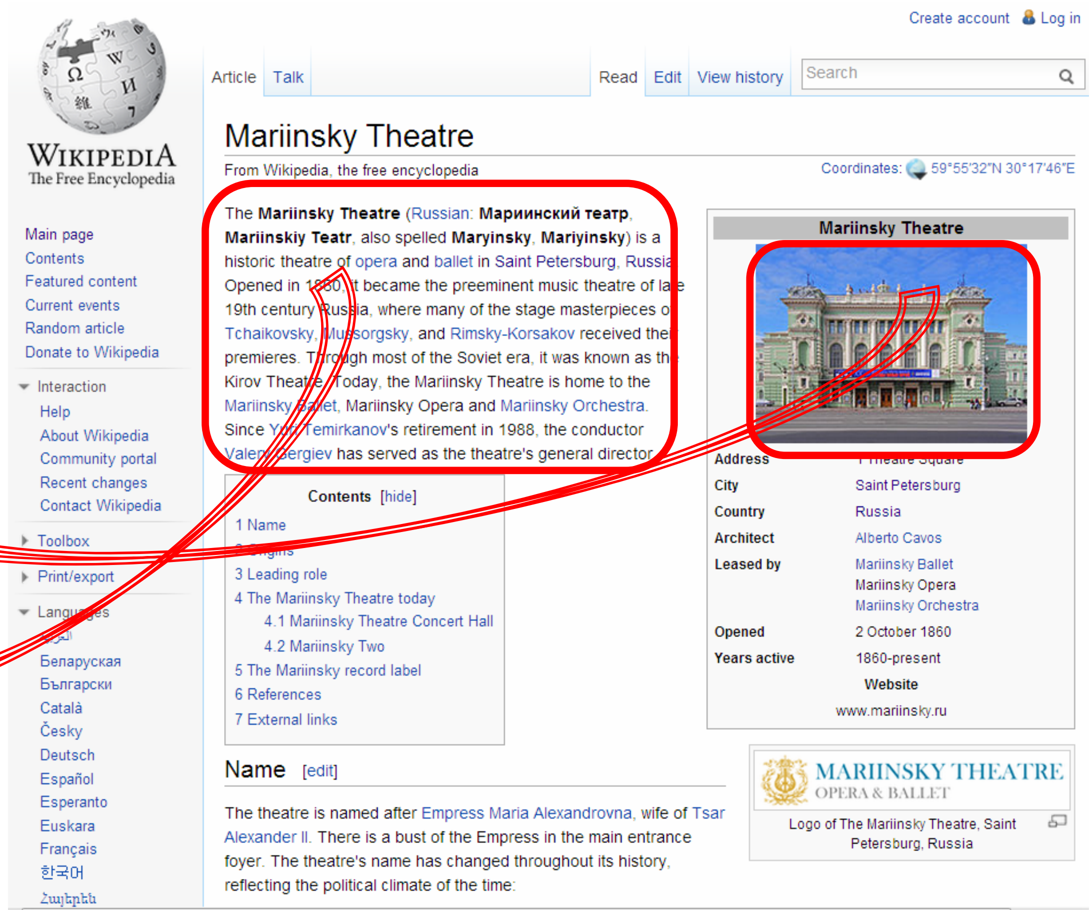
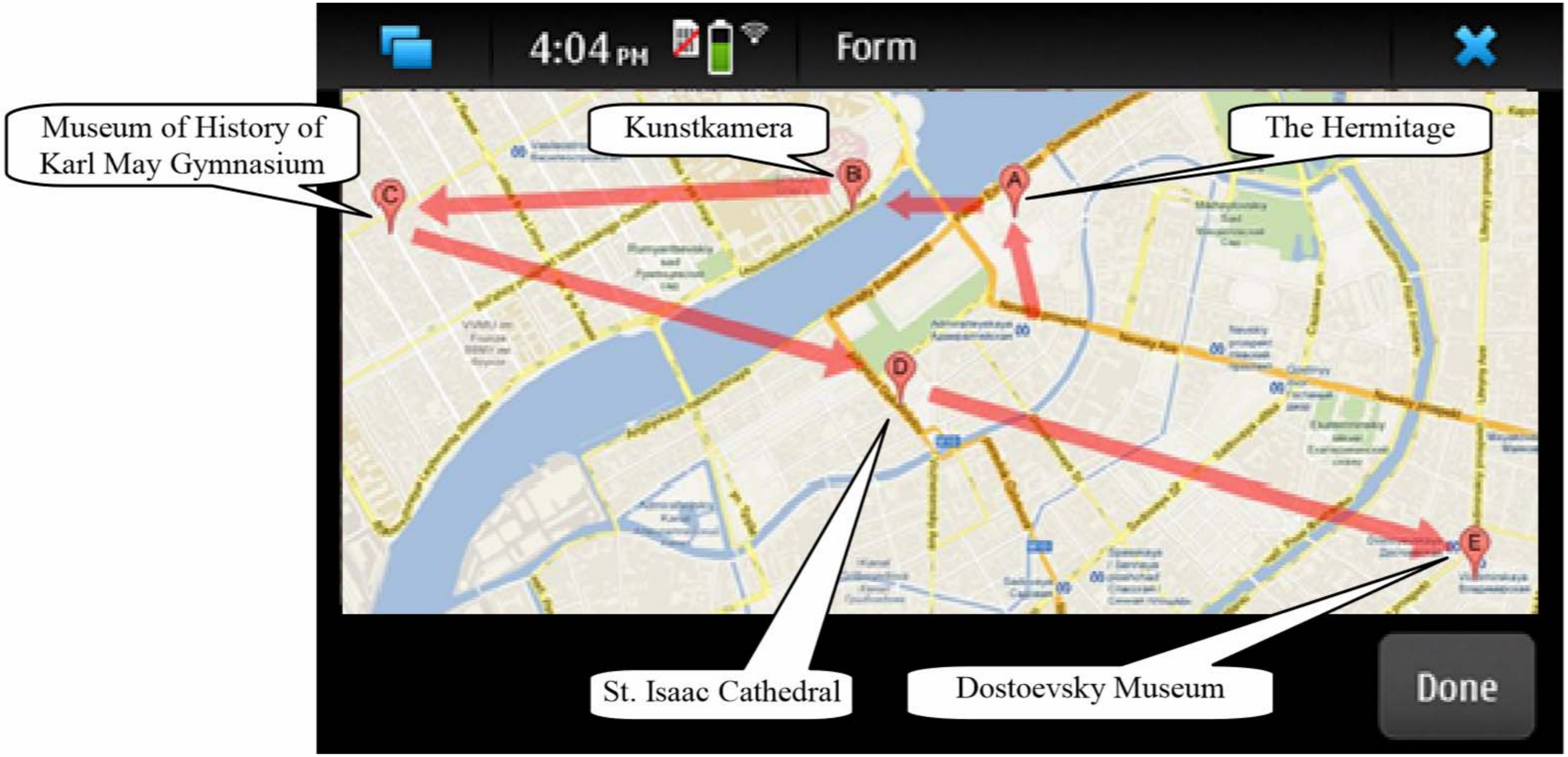


Mariinsky Theatre (, **Mariinskiy Teatr**, also spelled **Maryinsky**, **Mariyinsky**) is a historic theatre of opera and ballet in Saint Petersburg, Russia. Opened in 1860, it became the preeminent music theatre of late 19th century Russia, where many of the stage masterpieces of Tchaikovsky, Mussorgsky, and Rimsky-Korsakov received their premieres. Through most of the Soviet era, it was known as the Kirov Theatre. Today, the Mariinsky Theatre is home to the Mariinsky Ballet, Mariinsky Opera and Mariinsky Orchestra. Since Yuri Temirkanov's retirement in 1988, the conductor Valery Gergiev has served as the theatre's general director.



Case Study: e-Tourism

Museum Attending Plan Example



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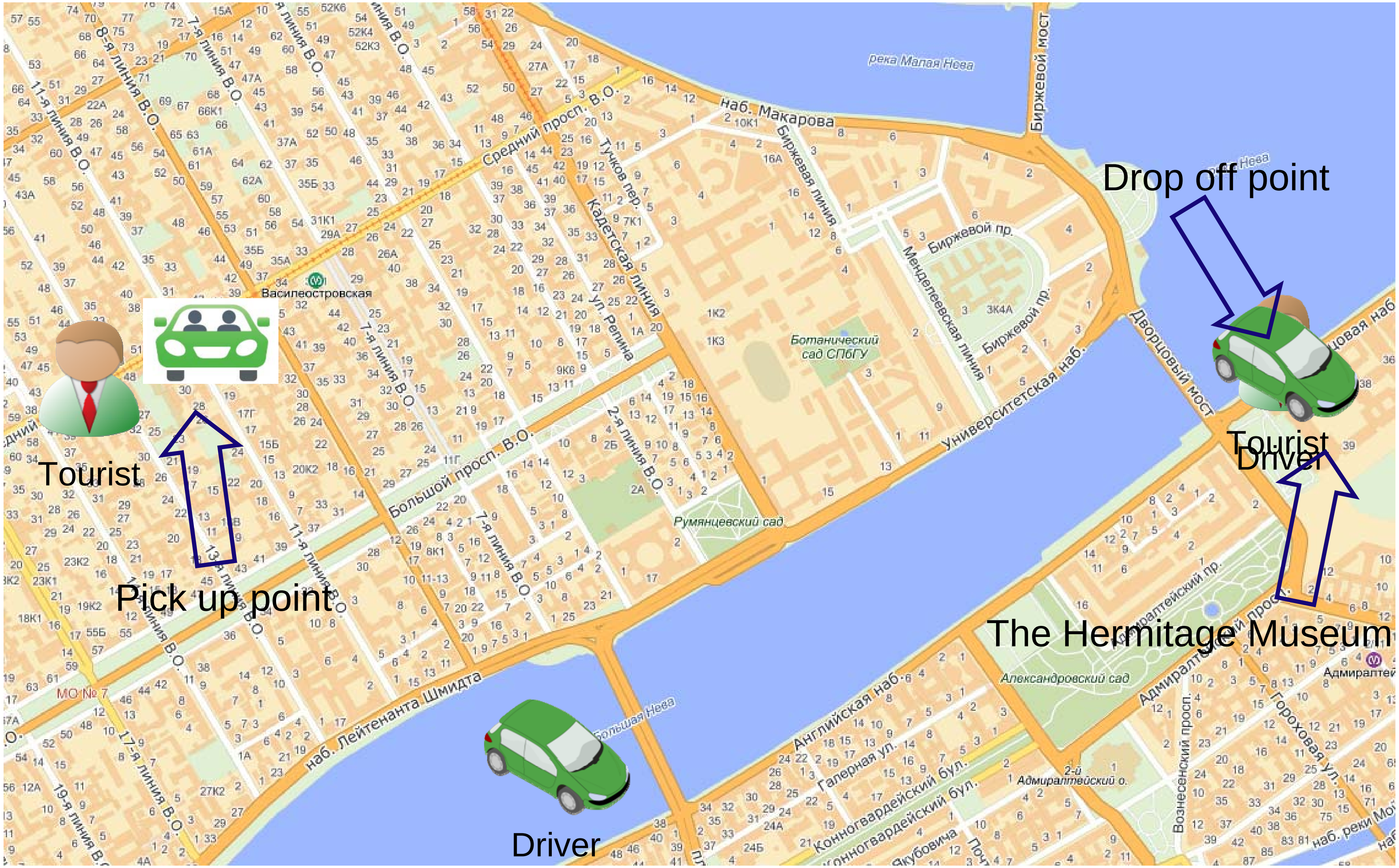
Case Study: e-Tourism

Ridesharing Service Scenario



Conclusion

- The context-driven knowledge integration *approach* for decision support *is originally problem-independent* and can be applied to different domains by creation of a new application ontology describing the new problems, and finding and attaching appropriate information & knowledge sources.
- Implementation of context-driven *methodology can significantly facilitate flexibility and response speed* of decision support systems for network-centric operations in dynamic environments.
- Implementation of Web-*services* together with context-driven interoperability *create an opportunity for fast development of scalable DSSs*.

Thank you!

Contact information: Prof. Alexander Smirnov

e-mail: smir@iias.spb.su; phone: +7 812 328 8071