Collective Adaptive Systems: Approaches and challenges

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1. Socio-technical CAS
2. CAS Design and operating principles
3. Design paradigm
4. Scenarios
5. Conclusions
Outline

1. Socio-technical CAS
2. CAS Design and operating principles
3. Design paradigm
4. Scenarios
5. Conclusions
Socio-technical Collective Adaptive Systems:

- Composed of different heterogeneous entities (e.g., individuals, groups, computers, software agents, devices, services, sensors) that may join and leave the collective at any time.

- Entities are operating at different temporal, spatial scales and social scope and interact collectively in complex manner with different objectives and goals.

- Their ability to be adaptive requires incorporating mechanisms that allow entities to perform actions that may lead to the emergence of a global desired behavior or service, while still managing and controlling the whole system behavior [1,2,3,14].
CAS can be organized into several layers according to time and space scales, and of increasing levels of complexity [15].
### Aspects of CASs

<table>
<thead>
<tr>
<th></th>
<th>Layer 1 CAS</th>
<th>Layer 2 CAS</th>
<th>Layer 3 CAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heterogeneous components</td>
<td>Mainly artificial entities (few human input)</td>
<td>Human, groups of human, artificial services</td>
<td>Communities, networks, social organizations</td>
</tr>
<tr>
<td>Many units/nodes</td>
<td>Dozens</td>
<td>Hundreds</td>
<td>Thousands</td>
</tr>
<tr>
<td>Unit with conflicting objectives and goals</td>
<td>Unique goal (no conflict)</td>
<td>Independent homogeneous goals with possible conflict</td>
<td>Social heterogeneous conflicting goals involving arbitration</td>
</tr>
<tr>
<td>Decision-making</td>
<td>User centric, centralized</td>
<td>Multi-user centric, decentralized</td>
<td>Social centric, decentralized</td>
</tr>
<tr>
<td>Emergence and control</td>
<td>Limited emergence and full control</td>
<td>Limited emergence and distributed control</td>
<td>Emergence of unexpected phenomena and fully distributed control</td>
</tr>
<tr>
<td>Nodes may join or leave</td>
<td>Rarely</td>
<td>Commonly</td>
<td>Continuously</td>
</tr>
<tr>
<td>Time scale</td>
<td>Short term (minutes, hours)</td>
<td>Medium term (from days to weeks and months)</td>
<td>Large (months, years)</td>
</tr>
<tr>
<td>Space scale</td>
<td>House / Building</td>
<td>Buildings / City</td>
<td>Metropolitan / Regional</td>
</tr>
<tr>
<td>Social scope</td>
<td>Limited</td>
<td>Bounded</td>
<td>Unbounded</td>
</tr>
</tbody>
</table>
Example: Mutual Assistance Community for Elderly People [15]
Example: cooperative driving [17]
Outline

1. Socio-technical CAS
2. CAS Design and operating principles
   - Information-aware communication protocols
   - Service discovery and composition mechanisms
   - Specification and verification techniques
   - Adaptive mechanisms
3. Design paradigm
4. Scenarios
5. Conclusions
Principles for engineering CAS are mainly classified into two categories:

- Design principles are necessary to build and manage the system by enabling the emergence of behaviour and facilitating prediction and control of those behaviours.

- Operating principles should define techniques that allow the system to operate taking into consideration the diversity of objectives within the system and the need to reason in the presence of uncertainty (e.g., partial, noisy, out-of-date and inaccurate information) [18].
Socio-technical CAS
CAS Design and operating principles
Design paradigm
Scenarios
Conclusions

Information-aware communication protocols
Service discovery and composition mechanisms
Specification and verification techniques
Adaptive mechanisms

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Information-aware communication protocols [10,11,12]:

- Sending the right information to the right place.

- Important information gets automatically replicated and propagated where it is needed.

- Sending redundant and massive information could also have negative effects (e.g. be stressful, confusing) on their decision making process.
## Communication technologies

### Traditional communication technologies

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Infrastructure-based</th>
<th>Infrastructureless</th>
<th>Vehicular communication technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GSM/GPRS</strong></td>
<td>V2I/V2V^i</td>
<td>V2I/V2V</td>
<td>V2I/V2V^i</td>
</tr>
<tr>
<td><strong>WiMAX</strong></td>
<td>V2I/V2V^i</td>
<td>V2I/V2V</td>
<td>V2I/V2V^i</td>
</tr>
<tr>
<td><strong>DVB/DAB</strong></td>
<td>I2V</td>
<td>V2V^i</td>
<td>V2V^i</td>
</tr>
<tr>
<td><strong>WLANs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>(a/b/g/n)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MM Wave</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IR</strong></td>
<td>1/2</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td><strong>ZigBee</strong></td>
<td>1/2</td>
<td>1/2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Bluetooth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DSRC/WAVE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CALM (M5)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Communication mode</strong></td>
<td>1.5–3.5 sec</td>
<td>~110 ms</td>
<td>~150 μs</td>
</tr>
<tr>
<td><strong>Directionality</strong></td>
<td>10–30 sec</td>
<td>~46 ms</td>
<td>Very Low</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>~100 ms</td>
<td>~16 ms</td>
<td>~100 ms</td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>80–384 kb/s</td>
<td>~1.73 Mb/s</td>
<td>~1 Mb/s</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>10 km</td>
<td>250 m</td>
<td>~100 m</td>
</tr>
<tr>
<td><strong>Transmission mode</strong></td>
<td>1/2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Limited</td>
</tr>
<tr>
<td><strong>Operating band</strong></td>
<td>0.8–1.9 GHz</td>
<td>5.8 GHz</td>
<td>5.8–5.9 GHz</td>
</tr>
</tbody>
</table>
### Information-aware communication protocols

- Service discovery and composition mechanisms
- Specification and verification techniques
- Adaptive mechanisms

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#### ITS applications

<table>
<thead>
<tr>
<th>Communication requirements</th>
<th>Safety applications</th>
<th>Efficiency applications</th>
<th>Comfort applications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Collision avoidance</td>
<td>Road sign notifications</td>
<td>Incident management</td>
</tr>
<tr>
<td></td>
<td>V2V/ V2I</td>
<td>V2V/ V2I</td>
<td>V2I/ V2I</td>
</tr>
<tr>
<td></td>
<td>1/2</td>
<td>1</td>
<td>1/2</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>Short</td>
<td>Short-medium</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1/3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>High</td>
<td>Medium-high</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
</tr>
</tbody>
</table>

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#### Communication mode

<table>
<thead>
<tr>
<th>Communication mode</th>
<th>Directionality</th>
<th>Latency</th>
<th>Range</th>
<th>Transmission mode</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2V/ V2I</td>
<td>One-way</td>
<td>Very low</td>
<td>In microseconds</td>
<td>1</td>
<td>Unicast</td>
</tr>
<tr>
<td>V2I</td>
<td>Two-way</td>
<td>Low</td>
<td>Medium</td>
<td>2</td>
<td>Geocast</td>
</tr>
<tr>
<td>V2I</td>
<td>Both</td>
<td>Average</td>
<td>In seconds</td>
<td>3</td>
<td>Broadcast</td>
</tr>
<tr>
<td>V2I</td>
<td>Both</td>
<td>Average</td>
<td>In seconds</td>
<td>3</td>
<td>Broadcast</td>
</tr>
</tbody>
</table>
Service discovery and composition mechanisms [13,14]:

- Describe how different services can be composed (at design or at runtime) into a coherent global service to satisfy the user request or to respond to changing context or human behaviour.
Resource Discovery Systems

Structured Systems
- Indexation
  - Centralized
  - Decentralized
- Distributed Hash Tables

Self-organized Systems
- Affinity network
  - Random walk
    - Cloning-based Walks
    - Learning-based Walks
  - Random Breadth-First Search
  - Breadth-First Search

Unstructured Systems
- Flooding
Specification, design, and runtime verification of CAS

- Static verification refers to proving the correctness of formally expressed specifications. Main techniques applied for static verification are Model Checking and Automated Theorem Proving.

- A relatively new direction of verification is runtime verification, which is defined as "the discipline of computer science that deals with the study, development, and application of those verification techniques that allow checking whether a run of a system satisfies or violates a given correctness property. [8,14,19]"
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Ambient Calculus</th>
<th>Bigraph</th>
<th>Temporal Logics</th>
<th>Ontology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movements</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Properties VS locations</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interactions</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concepts</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Relationships</td>
<td>Spatial</td>
<td>Spatial</td>
<td>Temporal</td>
<td>Any</td>
</tr>
<tr>
<td>Real-time constraints</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technique</th>
<th>Characteristic</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theorem Proving</td>
<td>Complete verification of the specification</td>
<td>State space explosion</td>
<td>Possible undecidibility</td>
</tr>
<tr>
<td>Model Checking</td>
<td>Complete verification of the specification</td>
<td>State space explosion</td>
<td>Possible undecidibility</td>
</tr>
<tr>
<td>Testing Specifications</td>
<td>No state space explosion</td>
<td>Partial verification of the specification</td>
<td></td>
</tr>
<tr>
<td>Runtime verification</td>
<td>Executing recovering strategies</td>
<td>Need of additional components for monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Partial verification of the implementation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tools</th>
<th>Ambient Calculus</th>
<th>Bigraph</th>
<th>Temp. Logics</th>
<th>Ontology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Modelling Tools</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algorithms for Model Checking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Checkers</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theorem Provers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reasoners</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Autonomic computing focuses on creating systems that manage themselves according to an administration goals, e.g., self-CHOP developed using MAPEK mechanism [5].

Control engineering field, most approaches emphasize positive and negative feedback loops seen also in natural and biological systems.

Software engineering communities highlighted that feedback loops are core design elements and should be made explicit for modeling, implementation, and validation approaches [4,7].
Negative and positive feedbacks are combined to insure stability of the system.

Positive feedback alone pushes the system beyond its limits and eventually out of control while negative feedback alone prevents the system from searching the optimal behavior [20,21].
CASs can be seen as a form of complex systems.

Complex Systems Science results have been also used only in a limited way by researchers in ICT for designing large-scale distributed adaptive systems.

Designing CAS requires a shift from the current top down design approach to a bottom up design approach. Local rules allow the system’s components to collaborate in a distributed manner in order to enable the emergence of behaviors at a global level [1,2].
how to design basic components in which decisions are distributed and not fully controlled by a single component.

how to design strategies (micro level) that allow the system to adapt to internal/external changes (macro level).

what are the dynamic rules that drive the system to the expected behavior.
Several techniques could be used to develop algorithms with increasing level of adaptiveness [16].
This paradigm shift requires an autonomic middleware that incorporates software elements or agents with adaptive capabilities [13,14].
Get inspired from features and capabilities seen in natural and biological systems, e.g., human brain, immune systems, Ants colony, Flocks of birds.

BIS provide several features and organizing principles that can guide the design of a scalable, adaptive and efficient framework to bring answers to CAS challenges [6,21].
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1 Socio-technical CAS
2 CAS Design and operating principles
3 Design paradigm
4 Scenarios
   - Scenario 1: TransportML for service interaction
   - Scenario 2: Snow clearance
   - Scenario 3: Geofencing
   - Scenario 4: Context-aware system
   - Scenario 5: eCall system
Increasing the driver safety and comfort by relaying required information using V2V.

The pervasive availability of wireless communication technologies and handheld devices and the emergence of GNSS infrastructures for LBS.

A platform and mechanisms are required to facilitate the development and deployment of LBS and hide details about technological infrastructures [9,10].
For developing such services, different infrastructure components are required: mobile devices, communication networks, positioning components, and service providers.
TransportML platform based on SOA principles is developed to enable interaction and collaboration of road-related services.

- Local entities services possess geographical information, which can be stored and formatted in many different ways.

- Service providers must agree on a common communication language: Transportation Markup Language (TransportML).

- TransportML is open, XML-based, extensible and it enables elaboration of the collaboration scenario at execution time.
This architecture allows providing value-added services, resulting from the collaboration between existing services maintained by different transport road entities.
Consists in Relay server and a LibMobileCom (LMC) library for V2I2V communications:

**Scenario 1: TransportML for service interaction**

**Scenario 2: Snow clearance**

**Scenario 3: Geofencing**

**Scenario 4: Context-aware system**

**Scenario 5: eCall system**

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A prototype is developed as a proof of concept.

- **Road status**
  - Provides information regarding the road status, issued by field agents
  - Comprises 2 sub-services: snow removal and roadwork services.

- **Waste Collection Service**
  - Provides information regarding the real-time location of waste collecting trucks.

- **Itinerary Computation Service**
  - Computes the fastest route between 2 locations
  - Allows defining waypoints, advised and discouraged areas.

- **Geofencing service**
  - Provides the characteristics of areas (granted or denied) based on vehicle characteristics.
Computed itinerary by calling LBS,

Scenario 1: TransportML for service interaction
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When using TransportML, the distance travelled is longer than the distance travelled when TransportML is not used.

The time required for the same travelling path is lower when TransportML is used.

The time needed to reach a destination is around 27% less when using TransportML.

The wireless communication delay versus V2I distance and the vehicle’s speed.

The average communication time is approximately 0.6s.
Track and display in real time the position of snow plow.

The roads to be cleared are known in advance and are stored in database or XML file.

Snow clearance service gets the road status whenever is invoked.

The road status (cleared or not) are based on an algorithm which from the snow plow position computes the unclear part of the itinerary.
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Define, draw geofences, store them in MySQL database, and represent them on the Map.

Define the characteristics of the geofences (e.g. max weight, forbidden vehicles).
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Scenario 1: TransportML for service interaction
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It is hard for drivers to anticipate dangerous situations on the road especially when driving during the night or in the fog, and due to the blurring of vision or at high speed.

Most of systems are based on centralized architectures and fixed infrastructures on roads.

Systems with the minimum of deployment cost and the ability for efficient context information transmission and processing are required.

Exchange information between vehicles experiencing undesirable and/or dangerous situations with other surrounding vehicles.
An in-vehicle embedded software is implemented and tested.

Extract information from the CAN bus of the vehicle and exchange this information with other nearby vehicles.
The data-logger software is developed using LabVIEW for extracting, decoding, and saving the frames coming from the vehicle CAN bus.
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Societal and technological progresses have brought a widespread diffusion of computer services characterized by an ever increasing complexity, pervasiveness, and social meaning.

These novel forms of social services and social organization constitute a promise of new solutions against the many new problems our societies are experiencing.

The current organizations are proving to be ineffective and unable to scale to the sizes of our new "big world".

Engineering the design of novel forms of collective adaptive services will make us able to turn the very same size of society into a source of valuable resources.

The exploitation of such resources requires the introduction of novel and smarter social organizations and principles, such as those based on a "self-serve society" [14,15].
Thank you for your attention.
References I


References II


References III


References IV


22  http://www.project-asset.com/