Technical University of Košice
Faculty of Electrical Engineering and Informatics
Department of Cybernetics and Artificial Intelligence

FUZZY COGNITIVE MAPS FOR CONTROL TASKS IN INTELLIGENT SPACE

Defense of PhD Proposal

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Reviewers: prof. Ing. Štefan Kozák, PhD.
doc. Ing. Szilveszter Kovács, PhD.
Ing. Ivana Budinská, PhD.

Presentation Outline

- Main goals of the dissertation ↓
- Main topics and contributions of the dissertation:
  - I. Artificial Intelligence & Situational Control ↓
  - II. Fuzzy Cognitive Maps for control of Complex Systems ↓
  - III. Internet of Things as a paradigm of Intelligent Spaces ↓
  - IV. Software tools for control of Intelligent Spaces using Fuzzy Cognitive Maps ↓
  - V. A proposal for control of an Intelligent Space ↓
- Conclusion ↓ & discussion ↓

Introduction

GOALS OF THE DISSERTATION

Main Goals

1. To modify the basic concept of fuzzy cognitive maps (FCM) in order to allow modeling and control of complex systems *(scientific goal)*.

2. To create a programming library for FCM computations applicable to modeling and control of complex systems, including auxiliary graphical user interface (GUI) and application programming interface (API) *(technological goal)*.

3. To propose a situational control model of an intelligent space utilizing FCM *(scientific goal)*.

4. To propose a control structure of an intelligent space for a situational class of robot navigation *(scientific goal)*.

5. To create a simulation of a situational control of elements of an intelligent space *(technological goal)*.

Part I. – Research foundation

ARTIFICIAL INTELLIGENCE & SITUATIONAL CONTROL

Means of Computational Intelligence

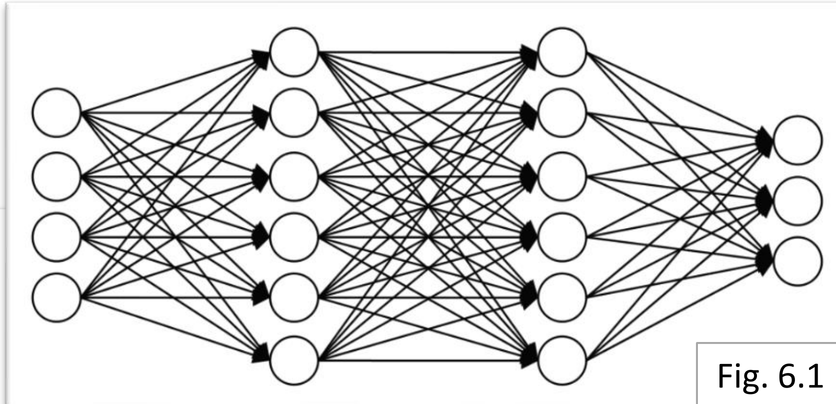


Fig. 6.1

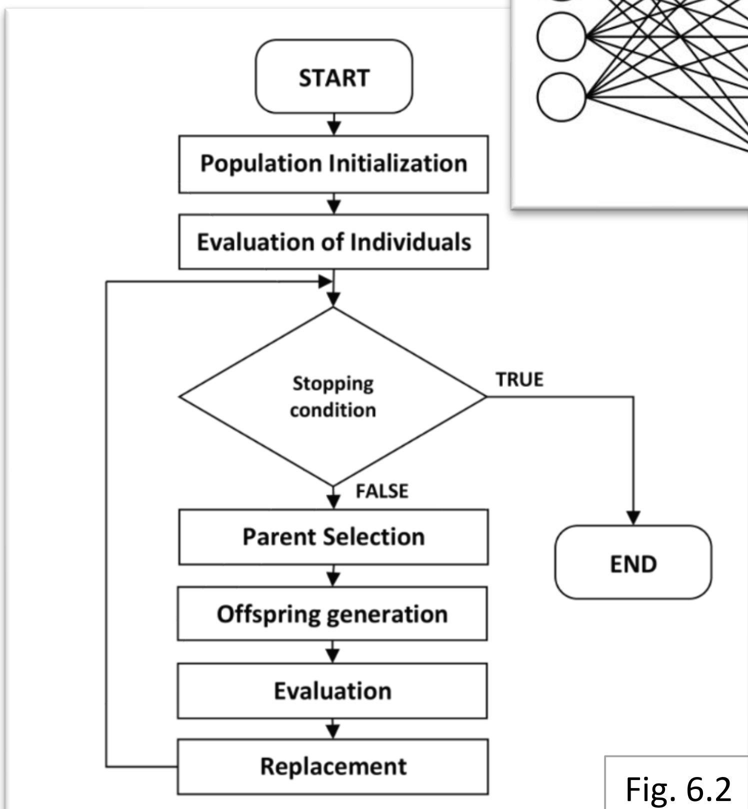


Fig. 6.2

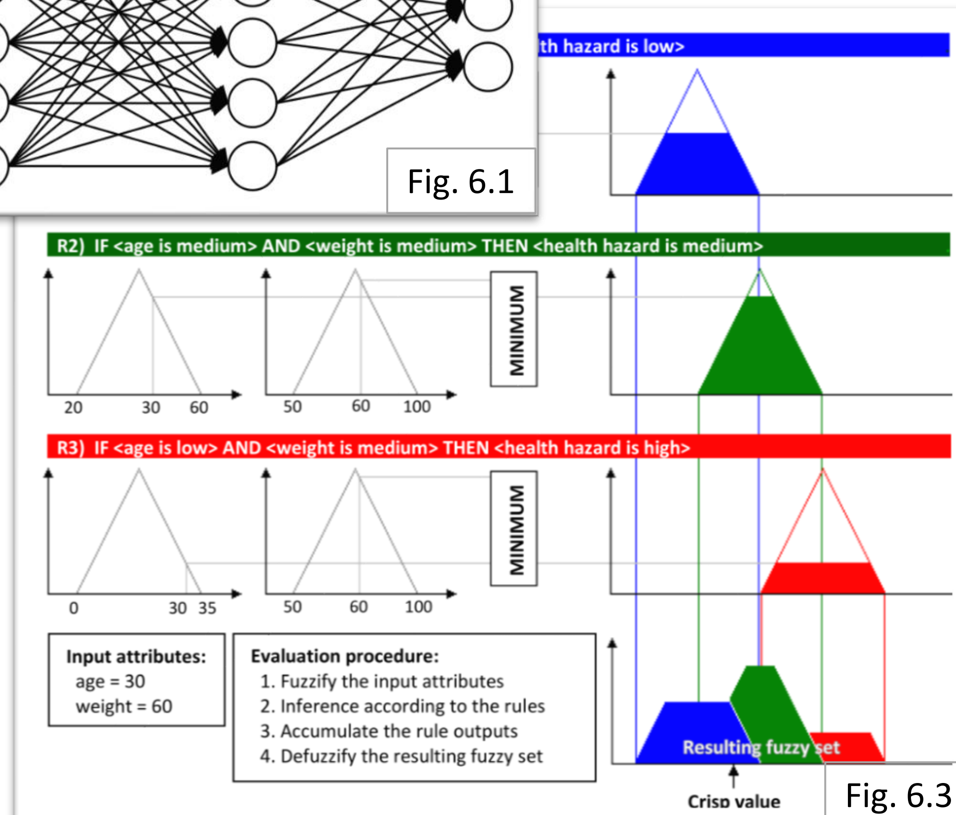


Fig. 6.3

Decomposition Control Methods Based on Computational Intelligence

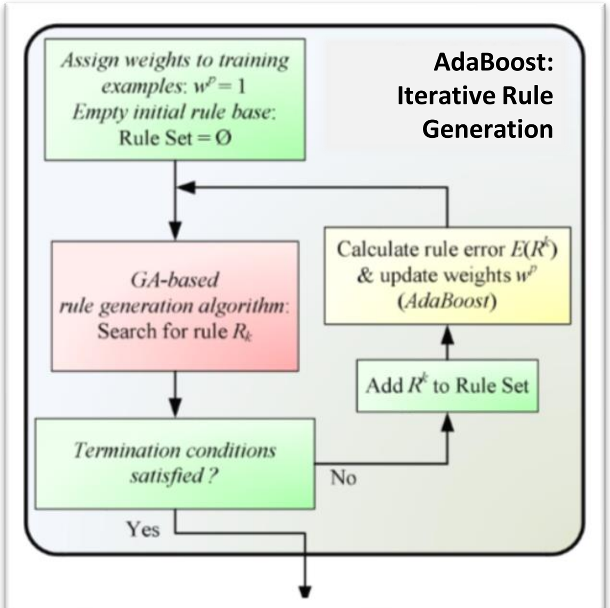


Fig. 7.1

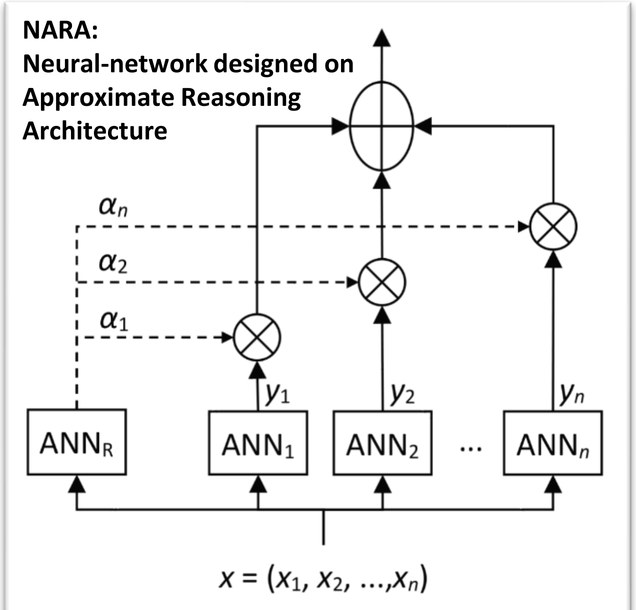


Fig. 7.2

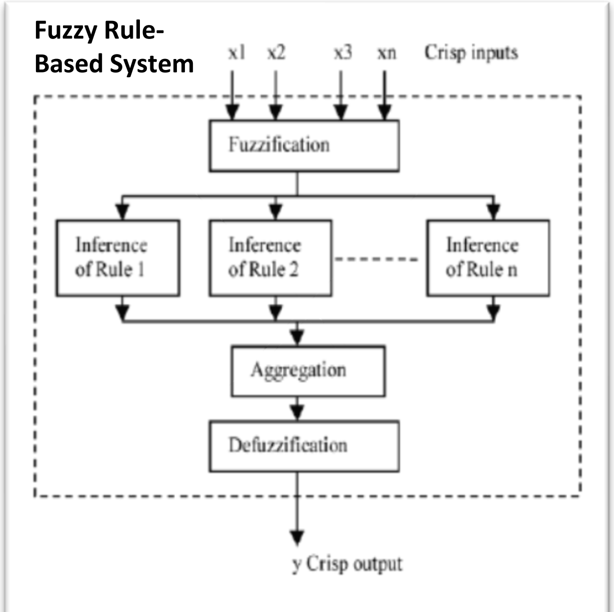


Fig. 7.3

Q1: Can narrow AI be more efficient, than one robust general AI ?
Q2: Can several narrow AIs be combined in order to form more general AI ?

Situational Control of Complex Systems

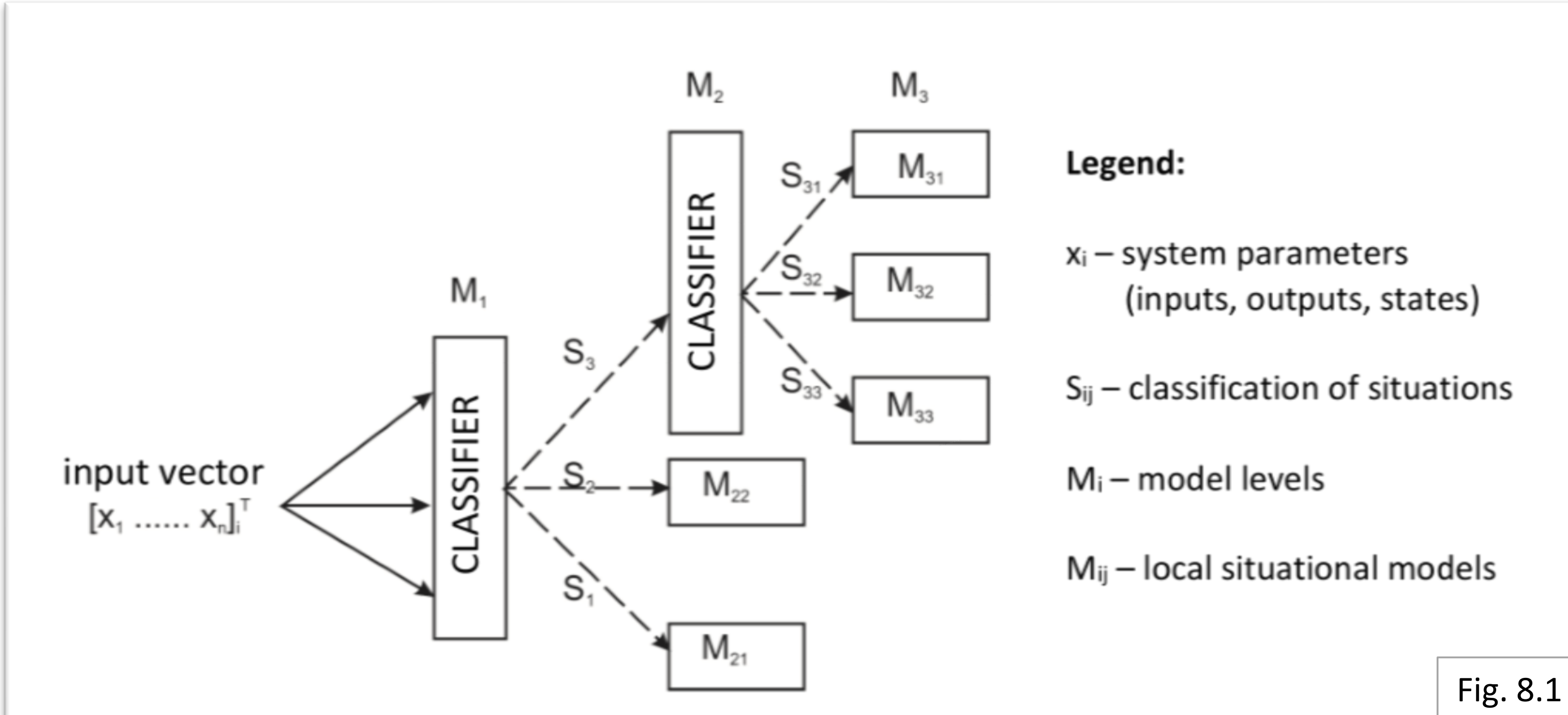


Fig. 8.1

Previous works:
Madarász, L., „Základné princípy situačného riadenia a formalizácie rozhodovacích procesov pri riadení zložitých hierarchických systémov." Kandidátska dizertačná práca, pp. 95, EF VŠT Košice, 1982.

Part II. – Research means

FUZZY COGNITIVE MAPS FOR CONTROL OF COMPLEX SYSTEMS

Fuzzy Cognitive Maps (FCM)

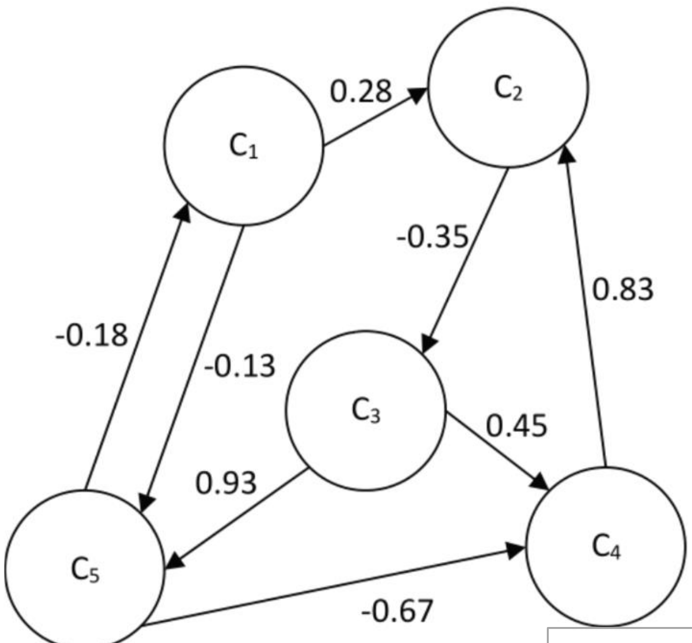


Fig. 10.1

$$
W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{array}
\begin{array}{c}
\begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \end{array} \\
\begin{pmatrix}
0 & 0{,}28 & 0 & 0 & -0{,}13 \\
0 & 0 & -0{,}35 & 0 & 0 \\
0 & 0 & 0 & 0{,}45 & 0{,}93 \\
0 & 0{,}83 & 0 & 0 & 0 \\
-0{,}18 & 0 & 0 & -0{,}67 & 0
\end{pmatrix}
\end{array}
$$

Fig. 10.2

Q3: Are qualitative methods of artificial intelligence (such as FCMs comparable to quantitative methods (such as ANNs)?

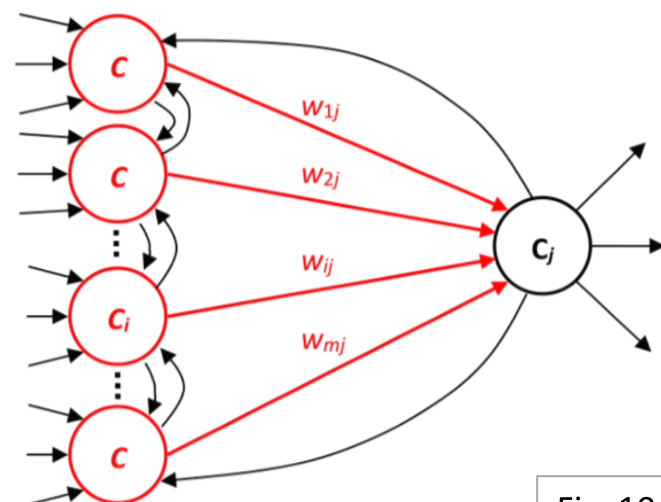


Fig. 10.3

Contributions to Modeling and Control of Complex Systems by FCMs

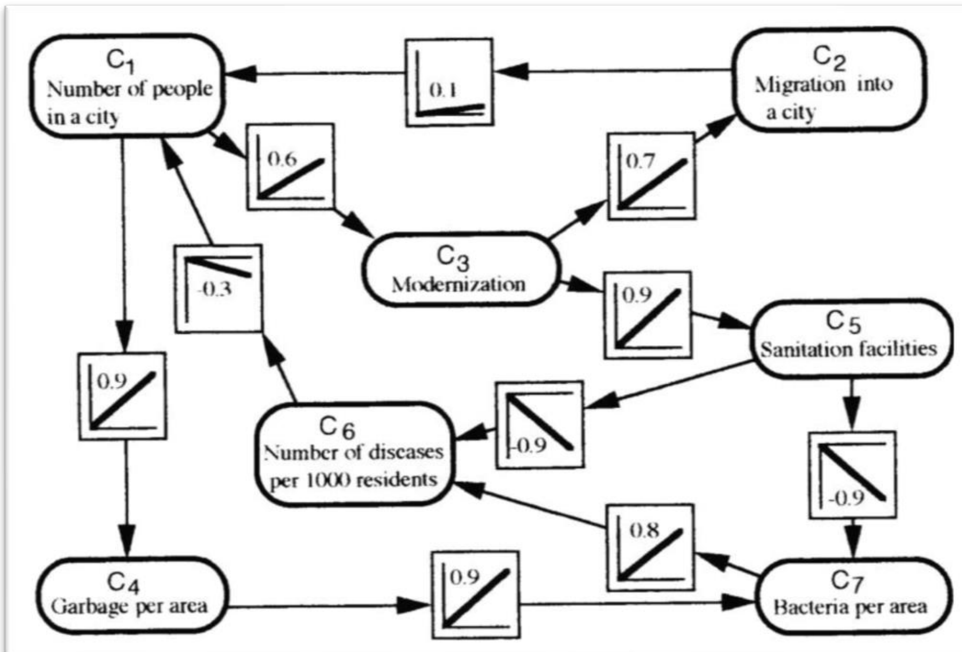


Fig. 11.1

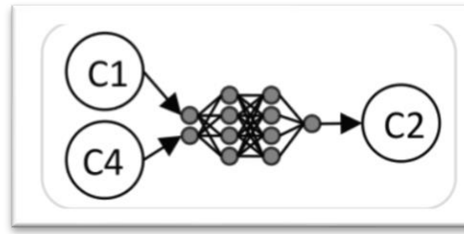


Fig. 11.2

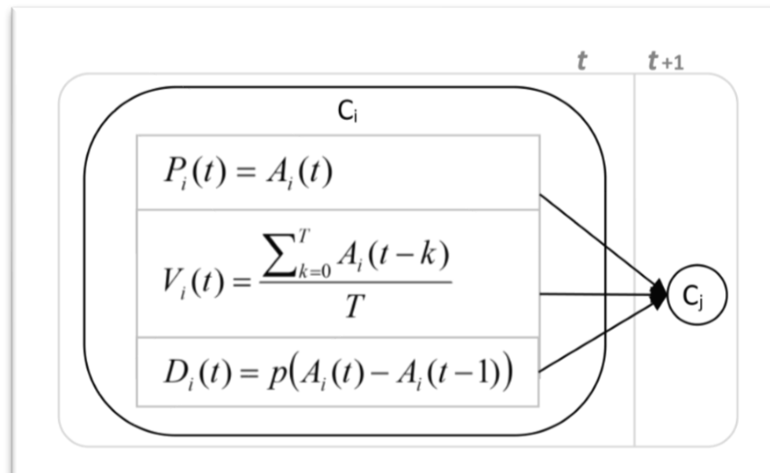


Fig. 11.3

Contribution (according to 1st Goal):
Puheim, M., Vaščák J., Madarász L. 2014. "Three-Term Relation Neuro-Fuzzy Cognitive Maps." In: CINTI 2014, November 19-21, 2014, Budapest. - Danvers : IEEE, 2014 P. 477-482. - ISBN 978-1-4799-5337-0

Contributions to Interactive Evolutionary Adaptation of FCMs

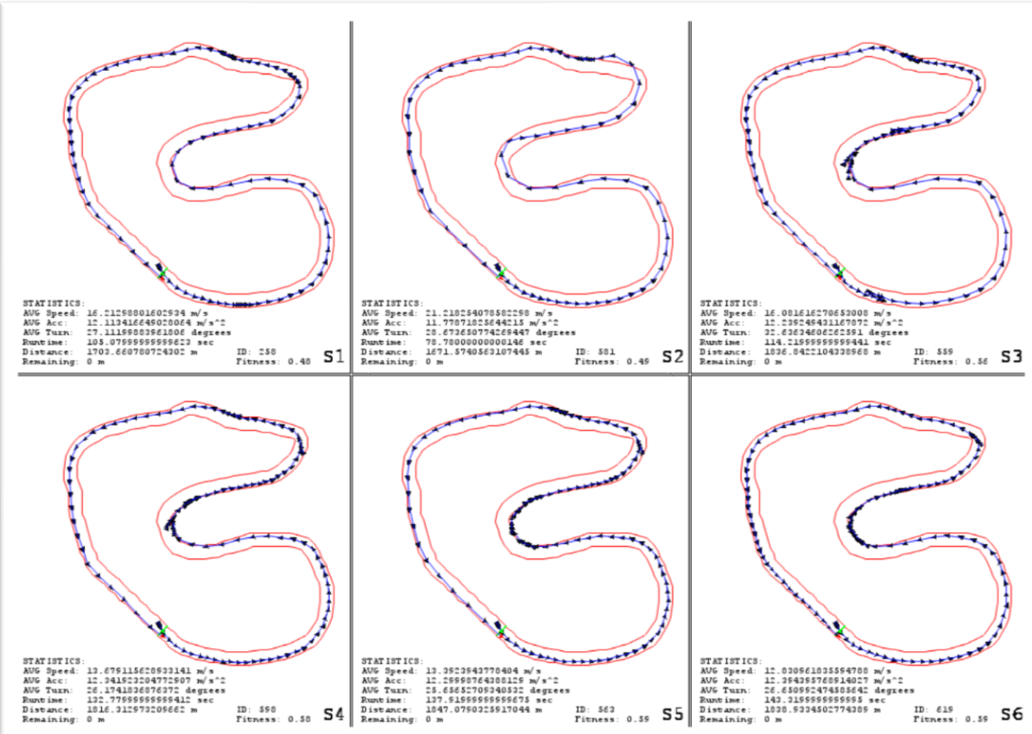


Fig. 12.1

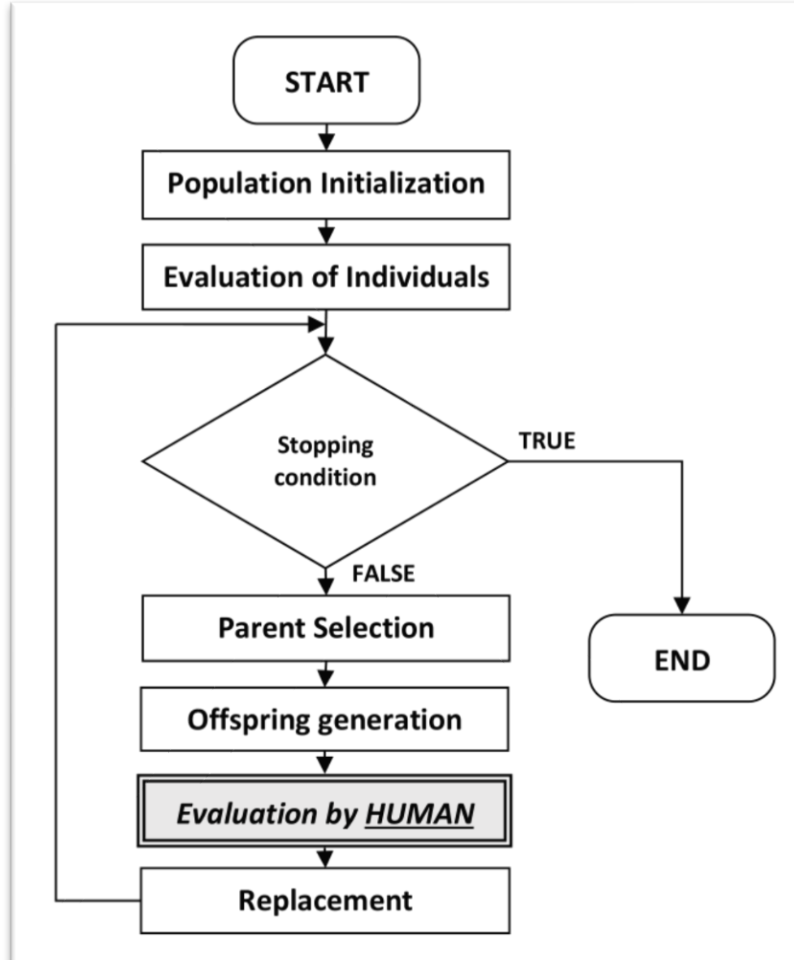


Fig. 12.2

Contribution (according to 1st Goal):
Mls, K., Cimler, R., Vaščák, J., Puheim, M. 2017. "Interactive evolutionary optimization of fuzzy cognitive maps." In: Neurocomputing. Vol. 232, p. 58-68. ISSN 0925-2312

Part III. – Application area

INTERNET OF THINGS AS A PARADIGM OF INTELLIGENT SPACES

Evolution of the Internet

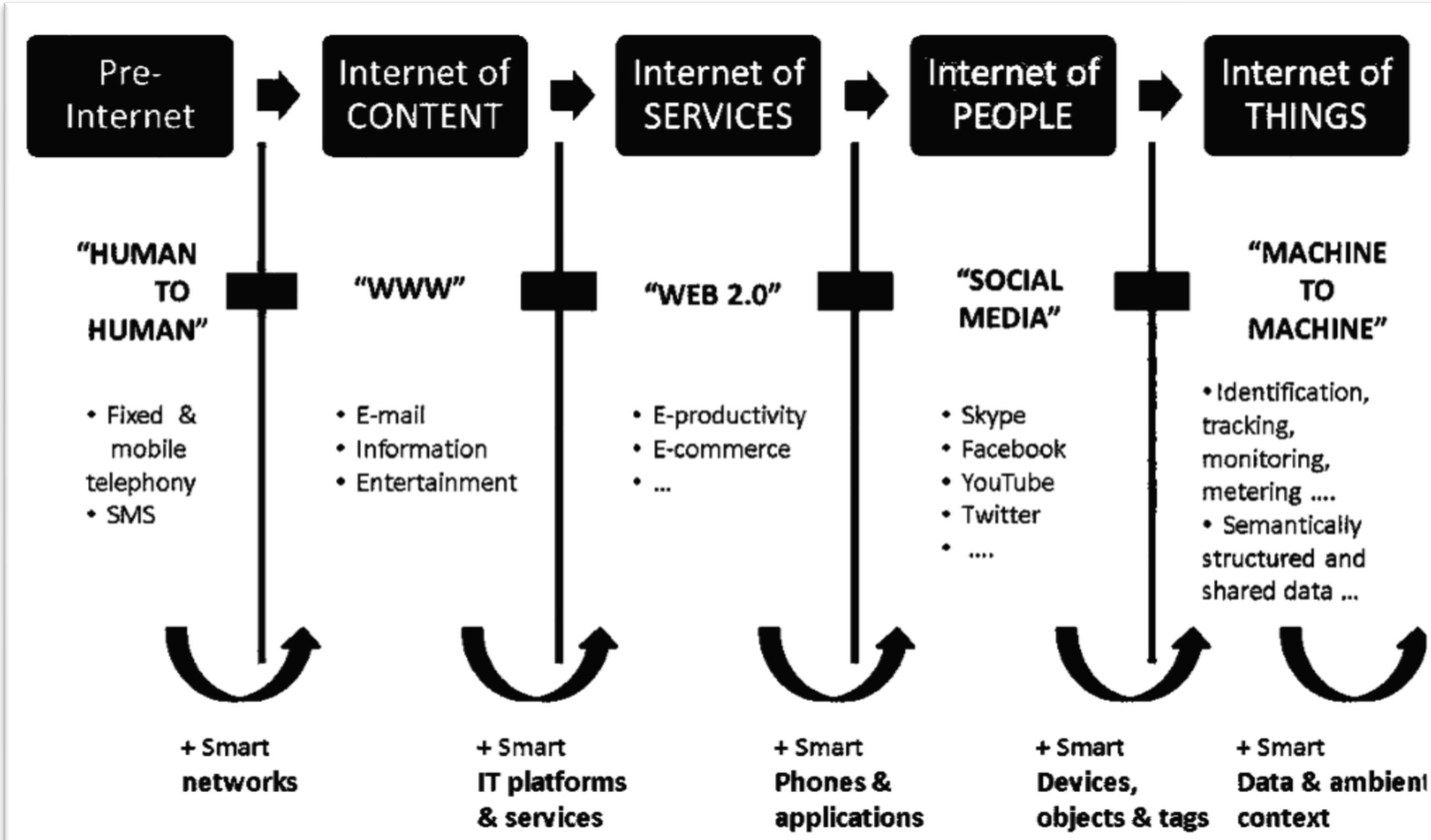


Fig. 14.1

Q4: Can we consider the Internet as a complex system?
Q5: Are future programs going to be provided as internet services?

Intelligent Space @ CIT

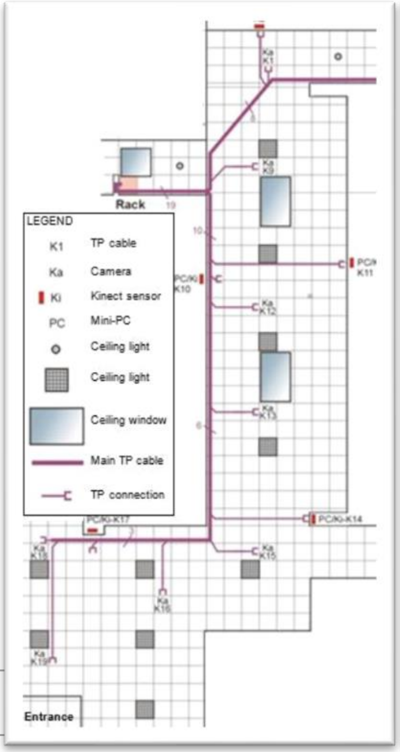


Fig. 15.1

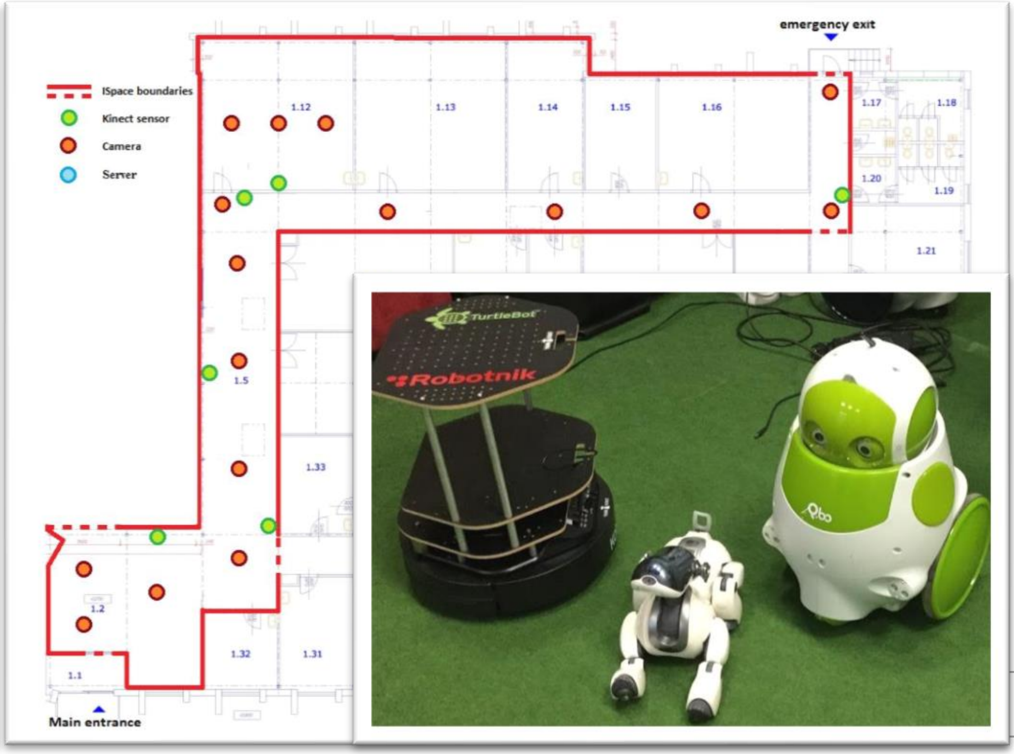


Fig. 15.2

Related works:
Hvizdoš, J. 2018. "Ubiquitous Robotics in Intelligent Space: New Approaches in Navigation of Ubiquitous Robots." PhD Thesis. Košice, FEEI, DCAI, TUKE.

Contributions to Intelligent Space

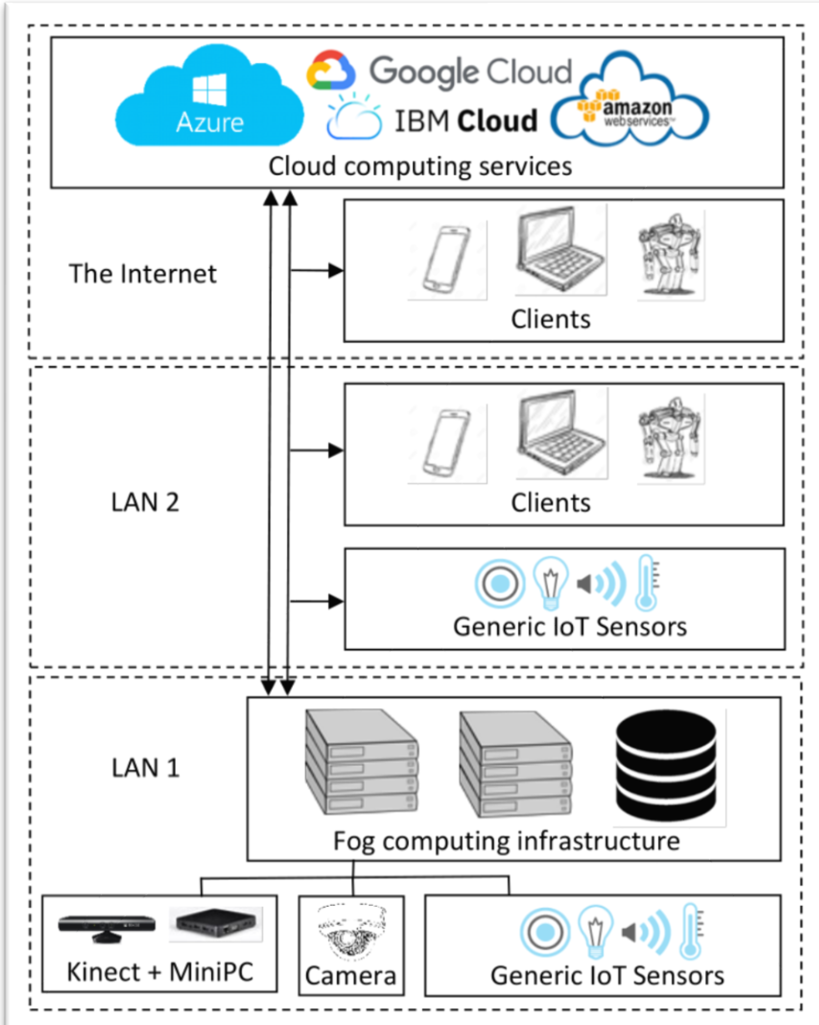


Fig. 16.1

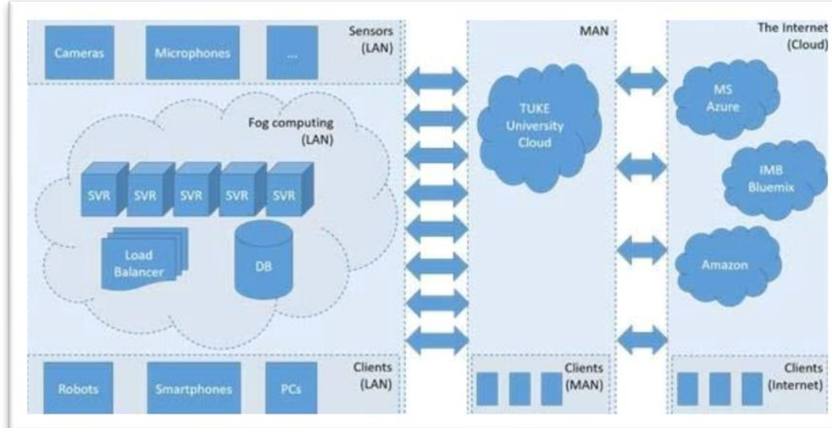


Fig. 16.2

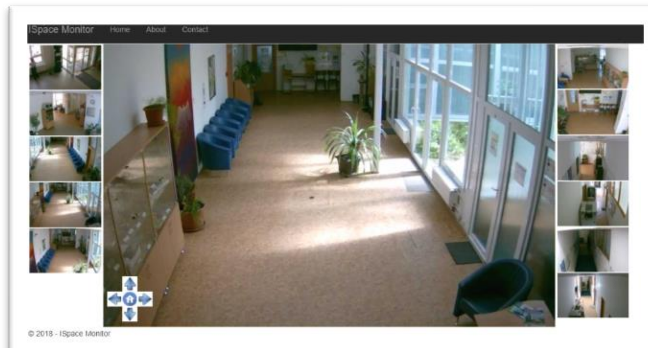


Fig. 16.3

Contribution: Čurová, D., Haluška, R., Hugec, T., Puheim M., Vaščák J., Sinčák, P. 2017. "Intelligent space at center for intelligent technologies – system proposal." In: SAMI 2017. - Danvers : IEEE, 2017 S. 191-195. - ISBN 978-1-5090-5654-5

Part IV. - Implementation

SOFTWARE TOOLS FOR CONTROL OF INTELLIGENT SPACES USING FUZZY COGNITIVE MAPS

Open Fuzzy Cognitive Maps Library

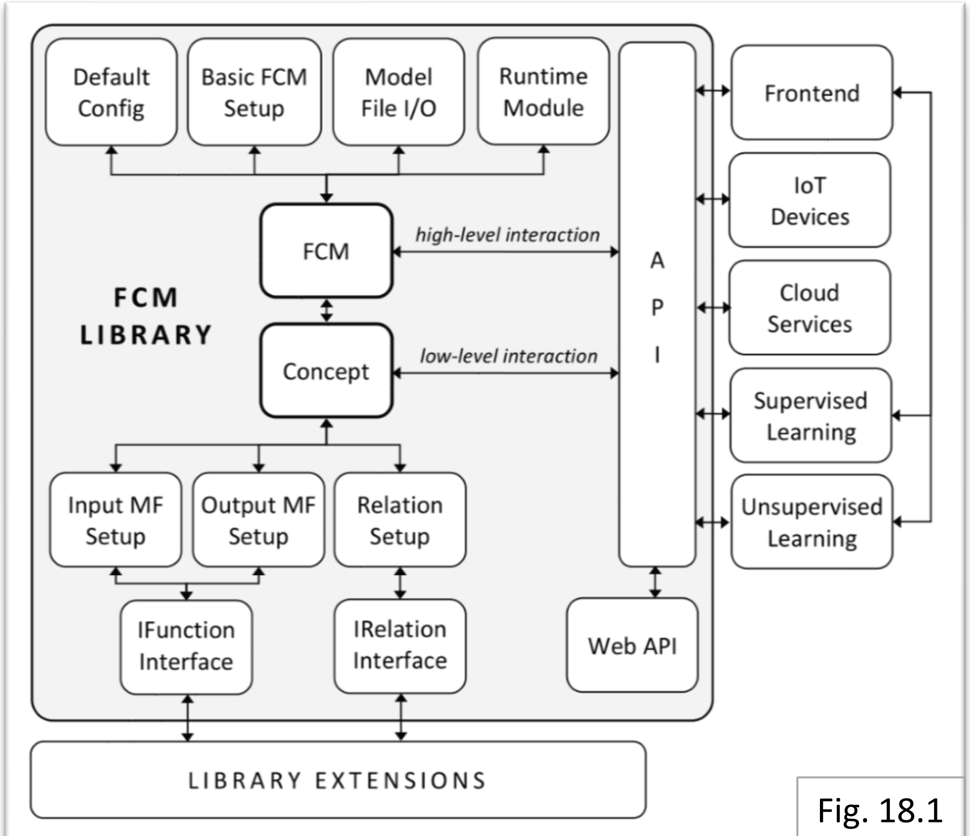


Fig. 18.1

Contribution (according to 2nd Goal):
Puheim, M., Vaščák, J., Madarász, L. 2015. "A Proposal for Multi-Purpose Fuzzy Cognitive Maps Library for Complex System Modeling." In IEEE 13 th International Symposium on Applied Machine Intelligence and Informatics. January 22–24, 2015. pp. 175-180. ISBN: 978-1-4799-8220-2

Web API for PyOpenFCM

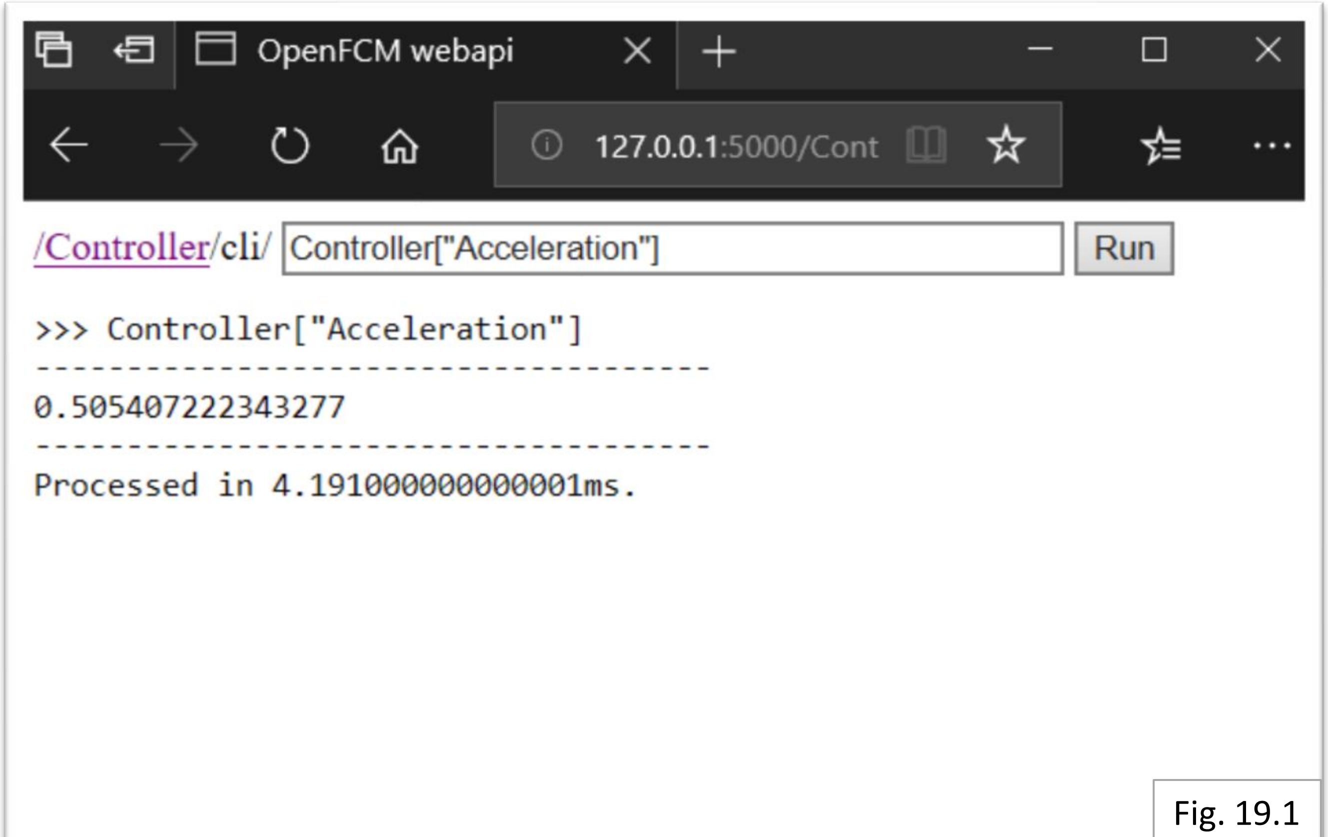


Fig. 19.1

Contribution (according to 2nd Goal):
Puheim, M. 2018. "PyOpenFCM - Python Open Fuzzy Cognitive Maps Library (with Web API)." GitHub source code repository. [Online]. Available: https://github.com/ mpuheim/PyOpenFCM

Part V. - Execution

A PROPOSAL FOR CONTROL OF AN INTELLIGENT SPACE

Situational Control of Intelligent Space

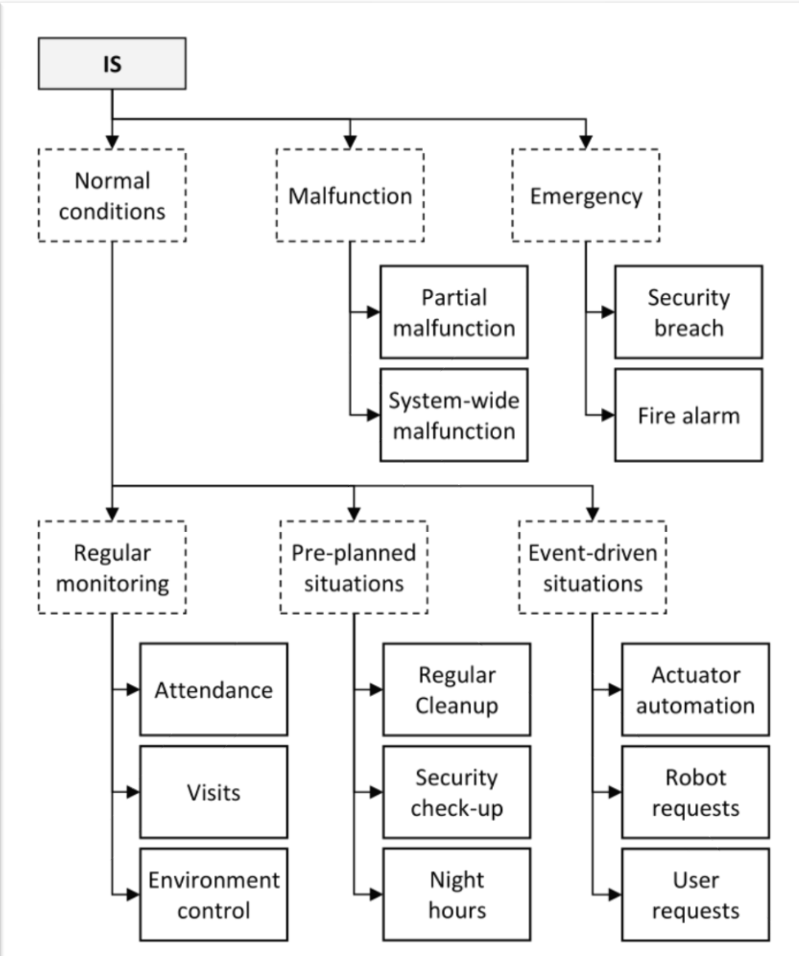


Fig. 21.1

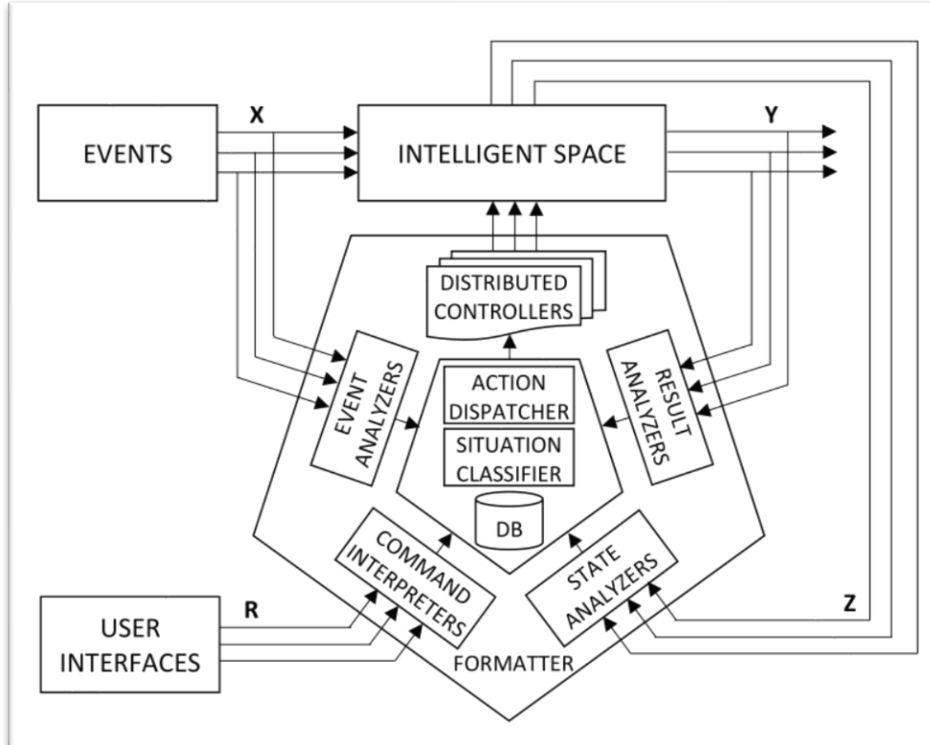


Fig. 21.2

Contribution to the 3rd Goal:
"To propose a situational control model of an intelligent space utilizing FCM"

Navigation of Mobile Robot in IS

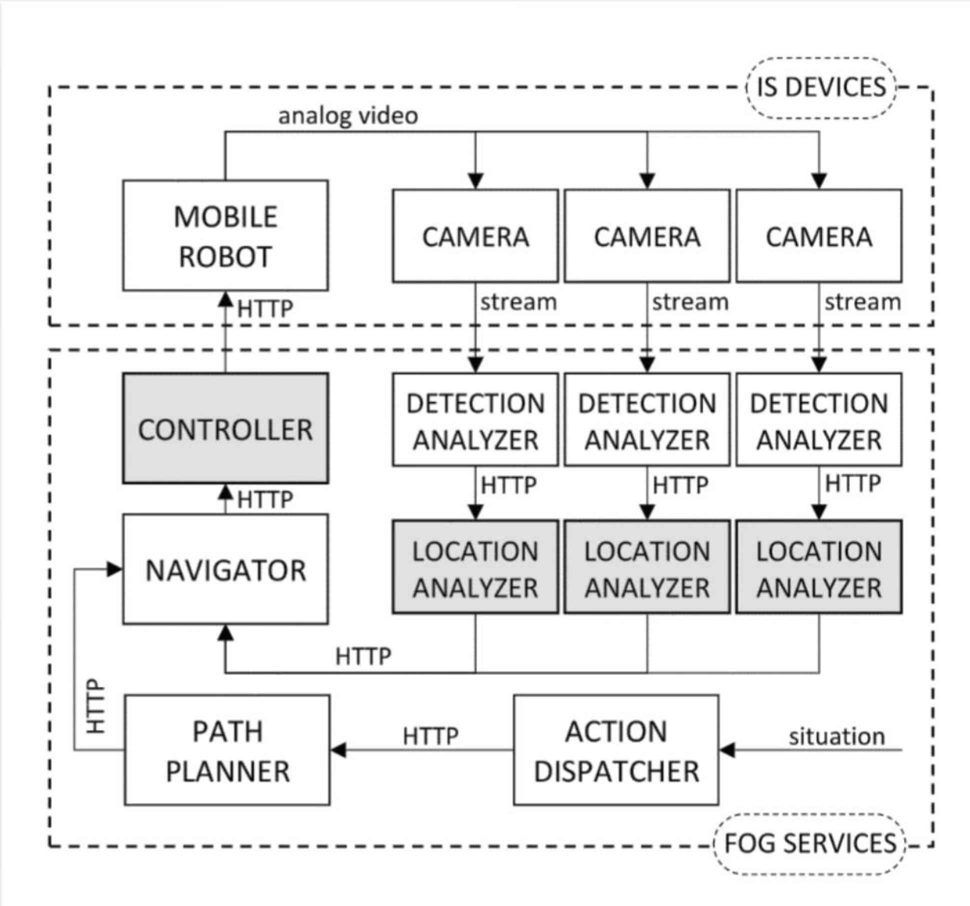


Fig. 22.1

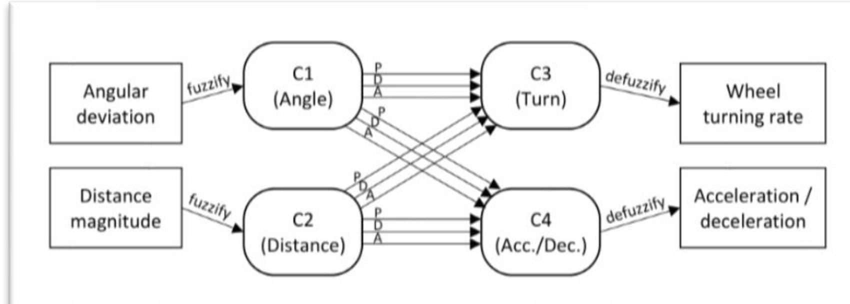


Fig. 22.2

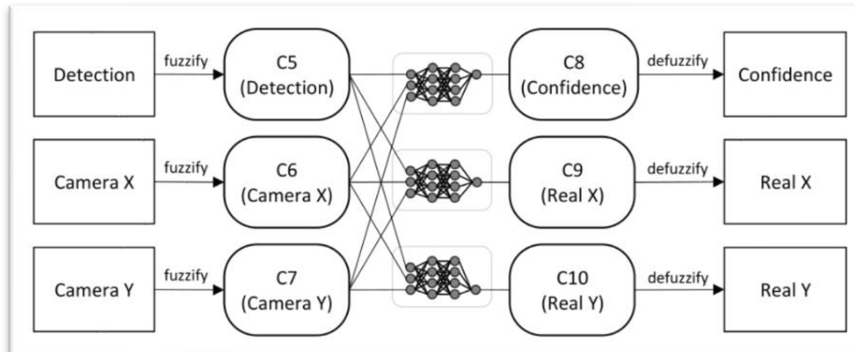


Fig. 22.3

Contribution to the 4th Goal:
"To propose a control structure of an intelligent space for a situational class of robot navigation"

Simulation Model of IS

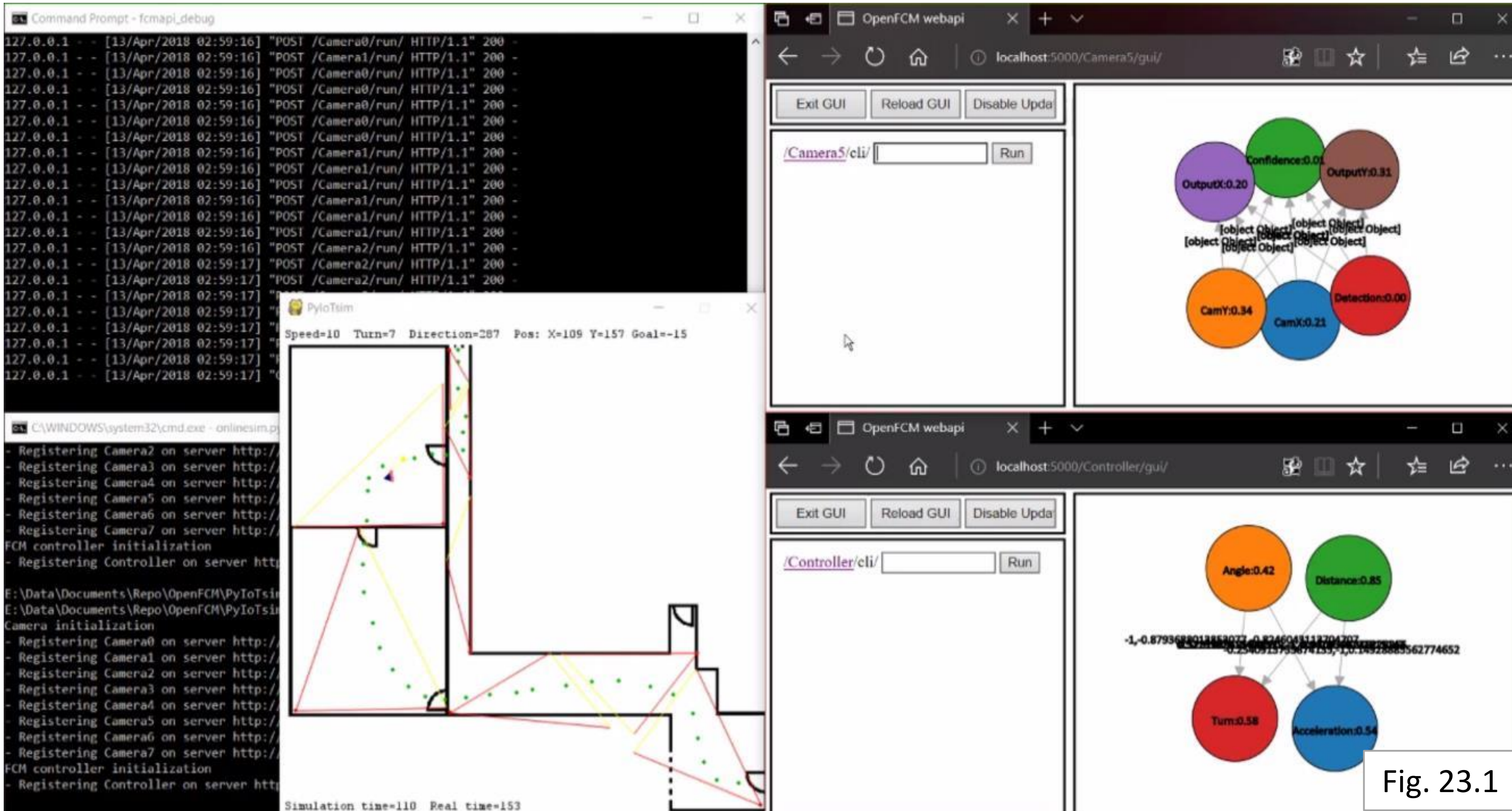


Fig. 23.1

Contribution to the 5th Goal:

"*To create a simulation of a situational control of elements of an intelligent space*"

Puheim, M. 2018. "PyIoTsim – Python IoT Simulator." GitHub source code repository. [Online]. Available: https://github.com/mpuheim/PyIoTsim

List of main contributions

CONCLUSION

Main contributions

- Proposal of extensions to:
  - FCM inference model by introducing **3-Term** and **Neural Relations**
  - FCM adaptation by introducing (semi-)**interactive evolutionary optimization**
- Creation of **software tools** which simplify and streamline **FCM design** and application.
- **Proposal** for situational control of an intelligent space and **proof-of-concept** simulation in selected situation class.

Thank you for your kind attention!

Ďakujem za pozornosť!

Köszönöm megtisztelő figyelmüket!

Appendix

REVIEWER QUESTIONS & ANSWERS

⌂

Question Index

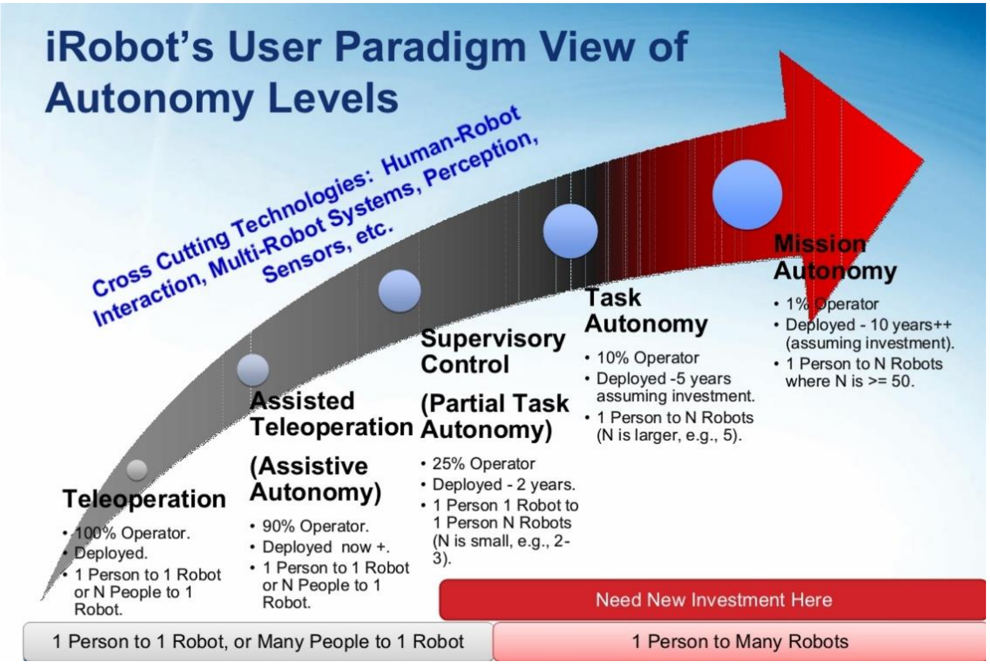
- Ing. Ivana Budinská, PhD. ⤓
- doc. Ing. Szilveszter Kovács, PhD. ⤓
- prof. Ing. Štefan Kozák, PhD. ⤓
- various discussion ⤓

Questions – Review 1

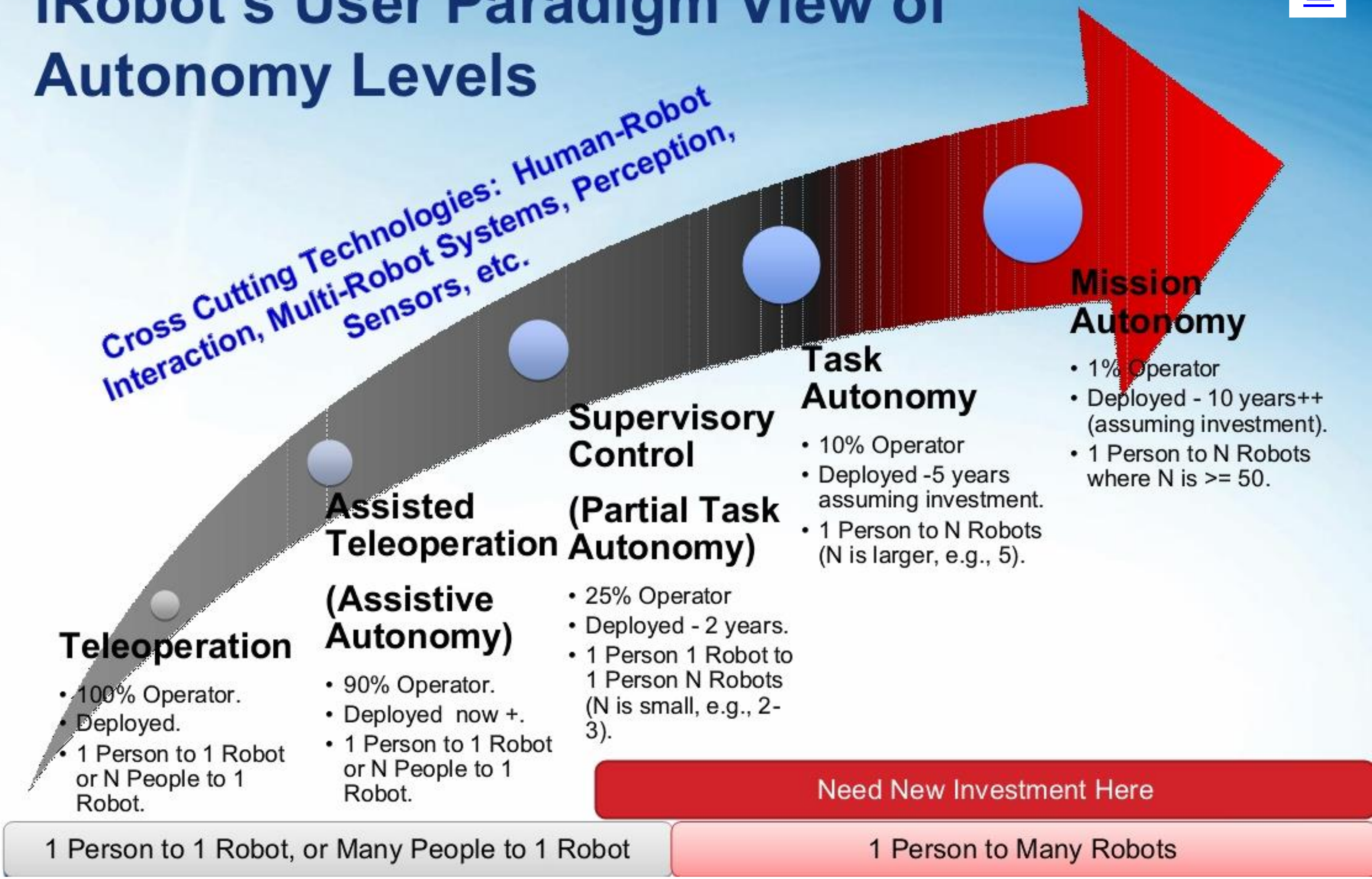
1. “You mention the degree of autonomy of intelligent elements, in the thesis. It would be useful to be able to distinguish the degrees of autonomy for intelligent devices, as it is, e.g., in case of autonomous vehicles. Do you know some methods or approach how to determine the degree of autonomy of intelligent elements?” ↓
2. “Safety and security is an important issue in intelligent environments and in IoT. What are the greatest security risks and threats and what one needs to focus on while implementing of, for example, intelligent home devices and applications?” ↓
3. “What is the time and computational complexity of the proposed methods and algorithms? How they could be optimized in order to apply them in real-world conditions?” ↓
4. “There are several use-cases suggested in chapter 7.1.2, Fig.61 – cleanups, patrols, user requested assistance. Could a control strategy and navigation method suggested as part of the thesis, be applied in dynamically changing environment?” ↓

Review 1 – Question 1

"You mention the degree of autonomy of intelligent elements, in the thesis. It would be useful to be able to distinguish the degrees of autonomy for intelligent devices, as it is, e.g., in case of autonomous vehicles. Do you know some methods or approach how to determine the degree of autonomy of intelligent elements?"



iRobot's User Paradigm View of Autonomy Levels



Review 1 – Question 2

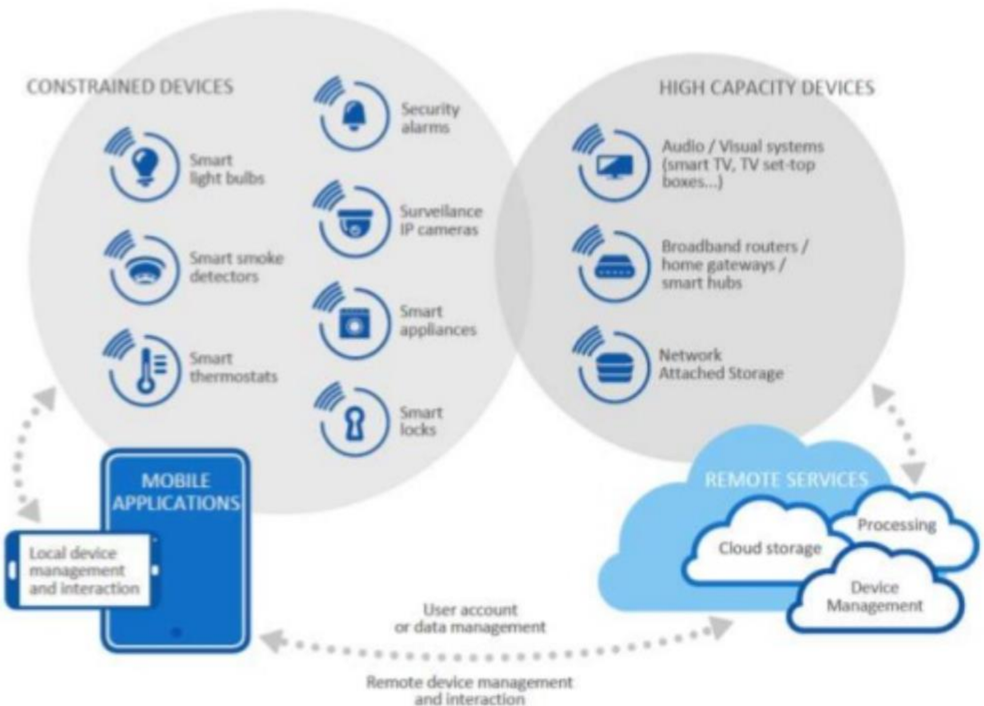
“Safety and security is an important issue in intelligent environments and in IoT. What are the greatest security risks and threats and what one needs to focus on while implementing of, for example, intelligent home devices and applications?”

Clip slide

IoT Cybersecurity – Smart Home

Threats

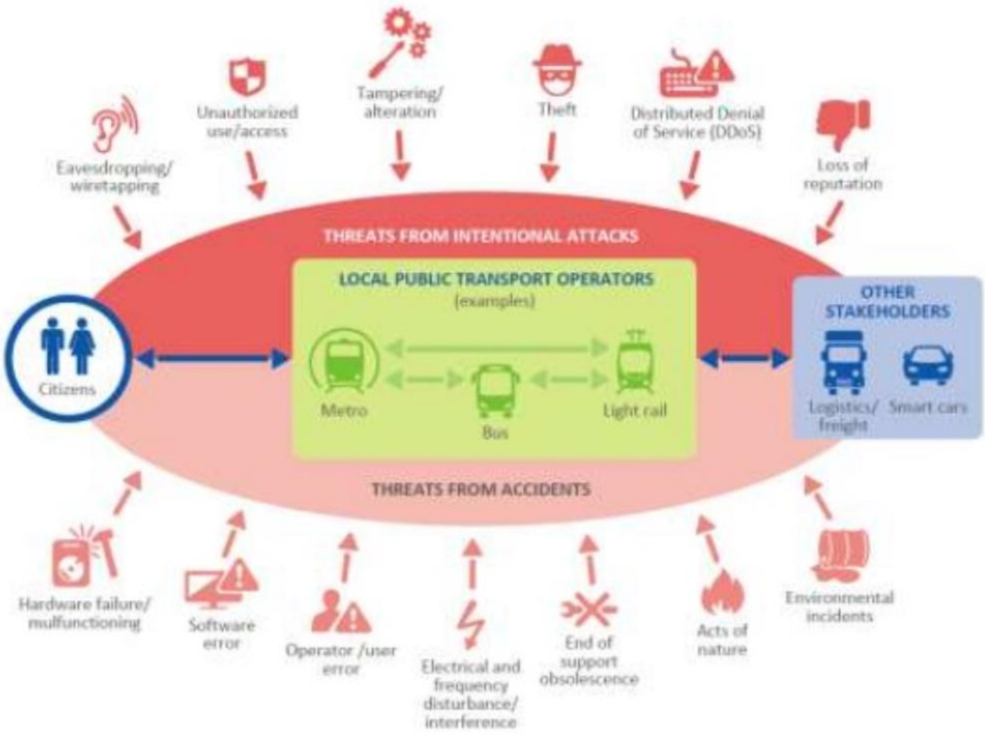
- Physical attacks
- Unintentional damage (accidental)
- Disasters and Outages
- Damage/ Loss (IT Assets)
- Failures/ Malfunctions
- Eavesdropping/Interception
- Hijacking as well as Nefarious Activity/Abuse



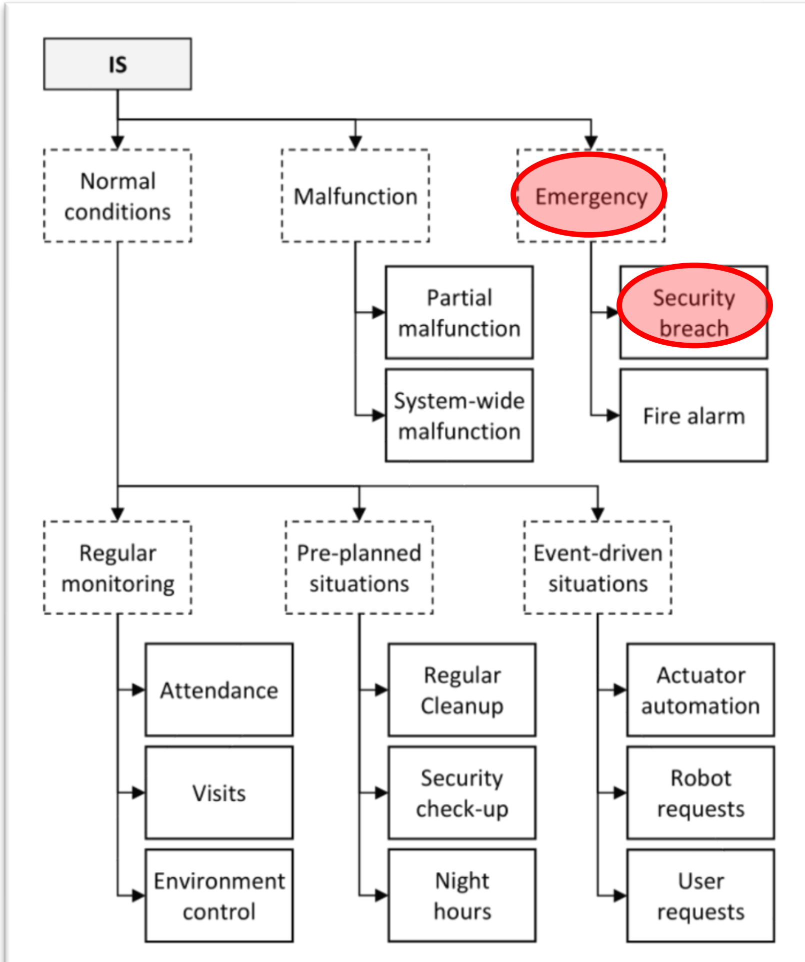
IoT Cybersecurity – Smart City

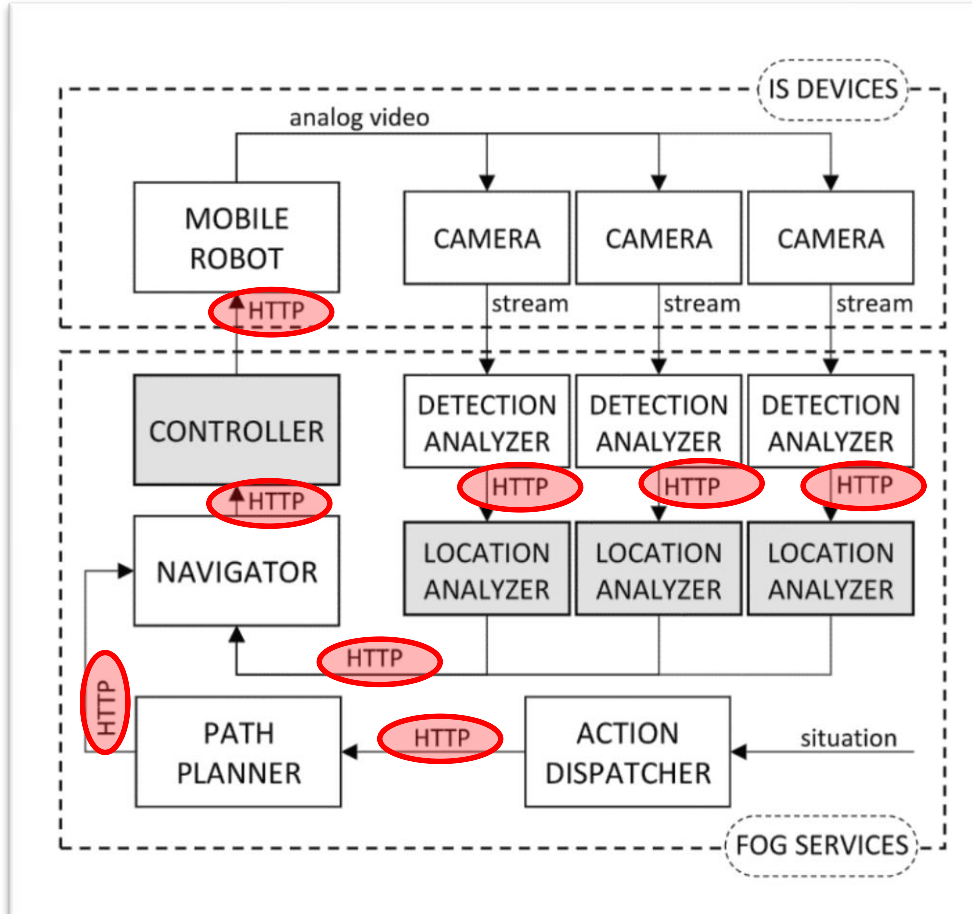
Protecting from Accidents

- Monitoring of KPIs
- Hardware Redundancy
- Shutdown Procedures
- Design Specification
- Maintenance Scheduling
- Response teams
- Quality assurance
- Reporting procedures
- Awareness
- Incident Reporting System
- Increase Resilience



Source: Cyber security for Smart Cities An architecture model for public transport by European Union Agency For Network And Information Security


IS
Normal conditions
Malfunction
Emergency
Partial malfunction
System-wide malfunction
Security breach
Fire alarm
Regular monitoring
Pre-planned situations
Event-driven situations
Attendance
Visits
Environment control
Regular Cleanup
Security check-up
Night hours
Actuator automation
Robot requests
User requests


IS DEVICES
analog video
MOBILE ROBOT
CAMERA
CAMERA
CAMERA
stream
stream
stream
HTTP
CONTROLLER
DETECTION ANALYZER
DETECTION ANALYZER
DETECTION ANALYZER
HTTP
HTTP
HTTP
HTTP
NAVIGATOR
LOCATION ANALYZER
LOCATION ANALYZER
LOCATION ANALYZER
HTTP
HTTP
PATH PLANNER
HTTP
ACTION DISPATCHER
situation
FOG SERVICES

Review 1 – Question 3

"What is the time and computational complexity of the proposed methods and algorithms? How they could be optimized in order to apply them in real-world conditions?"

$$
W = \begin{array}{c c}
 & \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \end{array} \\
\begin{array}{c} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{array} &
\begin{pmatrix}
0 & 0{,}28 & 0 & 0 & -0{,}13 \\
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0 & 0 & 0 & 0{,}45 & 0{,}93 \\
0 & 0{,}83 & 0 & 0 & 0 \\
-0{,}18 & 0 & 0 & -0{,}67 & 0
\end{pmatrix}
\end{array}
$$

$$A_j(t+1) = p\left(A_j(t) + \sum_{i=1; i \neq j}^{n} w_{ij} A_i(t) \right)$$

Dense matrix:
~ ***O*(*n*²)** → ~ $\boldsymbol{O(n^2)}$

Sparse matrix:
~ $\boldsymbol{O(s*n)}$

⌂

Computational complexity of sparse FCM:

- CPU performance = typically @ 3.0 GHz = **300 000 000 cycles per 0.1s**
- Sum/product of 2 numbers ≈ 10 cycles
- Computation of concept activation:

$$A_j(t+1) = p\left(A_j(t) + \sum_{i=1; i \neq j}^{n} w_{ij} A_i(t) \right)$$

  - *n* products + *n* sums + thresholding ≈ 10*n* + 10*n* + 100 ≈ **20*n*+100**
- Computation of FCM update:
  - number of concepts * (20*n*+100) ≈ ***p*(20*n*+100)**

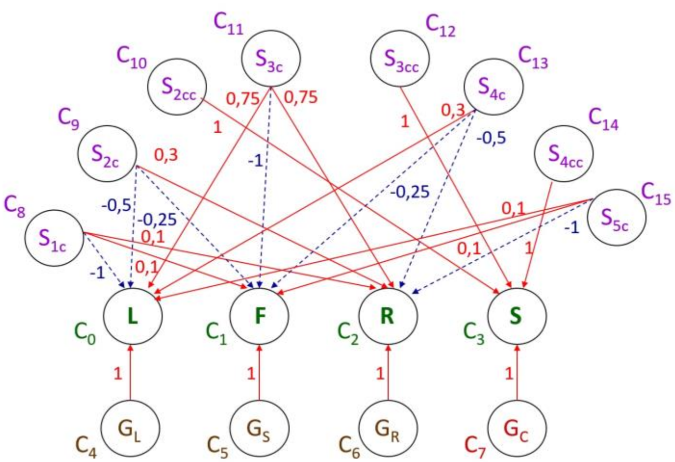
Num. of concepts	Inputs per concept	CPU cycles	CPU utilization
20	20	10 000	0.003%
200	40	180 000	0.060%
2 000	400	16 200 000	5.400%
15 000	**995**	**300 000 000**	**100%**
30 000	2 000	1 203 000 000	401%

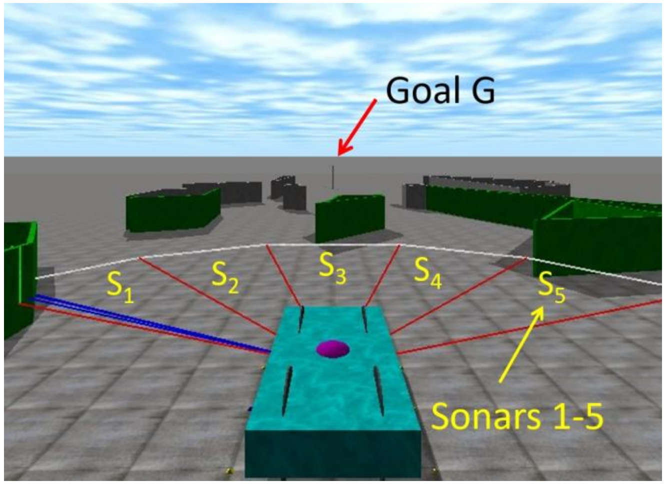
Contribution:

- Puheim, M., Vaščák, J., Machová, K. 2016. "Efficient FCM computations using sparse matrix-vector multiplication." In: SMC 2016. Danvers:IEEE. pp. 4165-4170. ISBN 978-1-5090-1819-2
- Puheim, M. 2016. "Sparse Matrix Vector Multiplication Benchmark." GitHub source code repository. [Online]. Available: https://github.com/mpuheim/SMVM-Benchmark

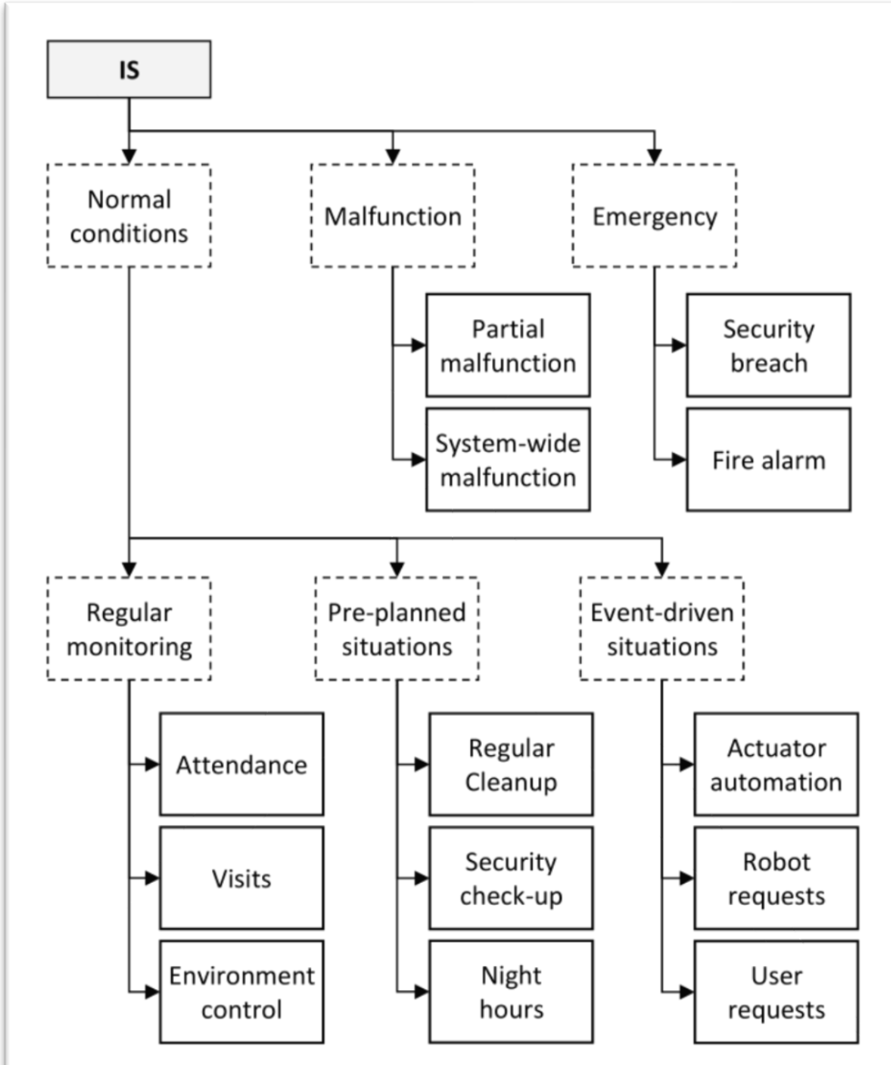
Review 1 – Question 4

"There are several use-cases suggested in chapter 7.1.2, Fig.61 – cleanups, patrols, user requested assistance. Could a control strategy and navigation method suggested as part of the thesis, be applied in dynamically changing environment?"





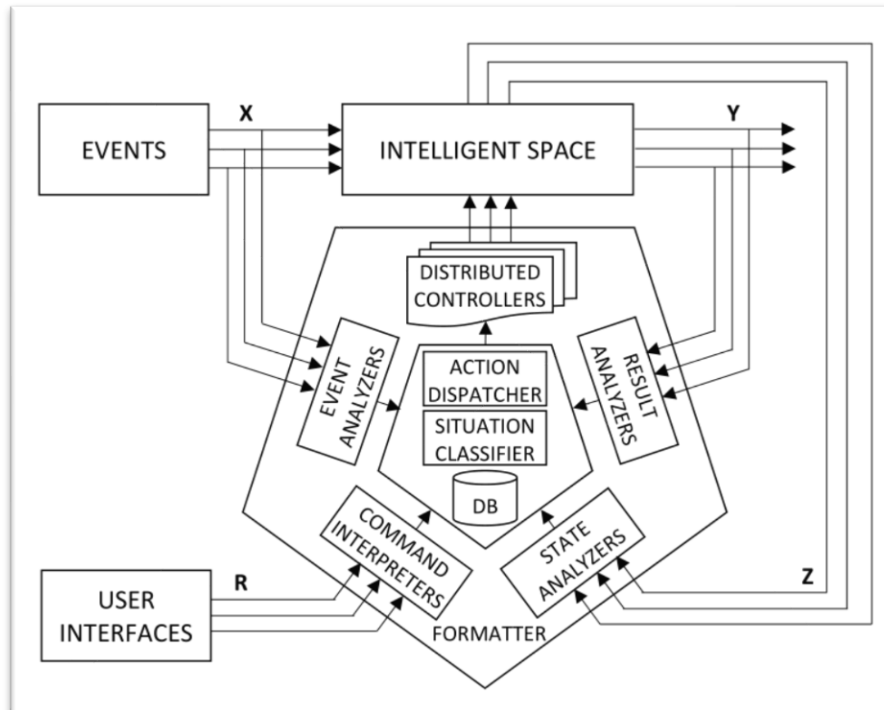
Related works:
Vaščák, J., Madarász L. 2010. "Adaptation of Fuzzy Cognitive Maps – a Comparison Study," Acta Polytechnica Hungarica, Vol. 7, No. 3, pp. 109-122.



Situational control assumes that:

"A single control strategy may and should be used for several situational classes."

"The strategy is parameterized at its initiation according to current system parameters."



Questions – Review 2

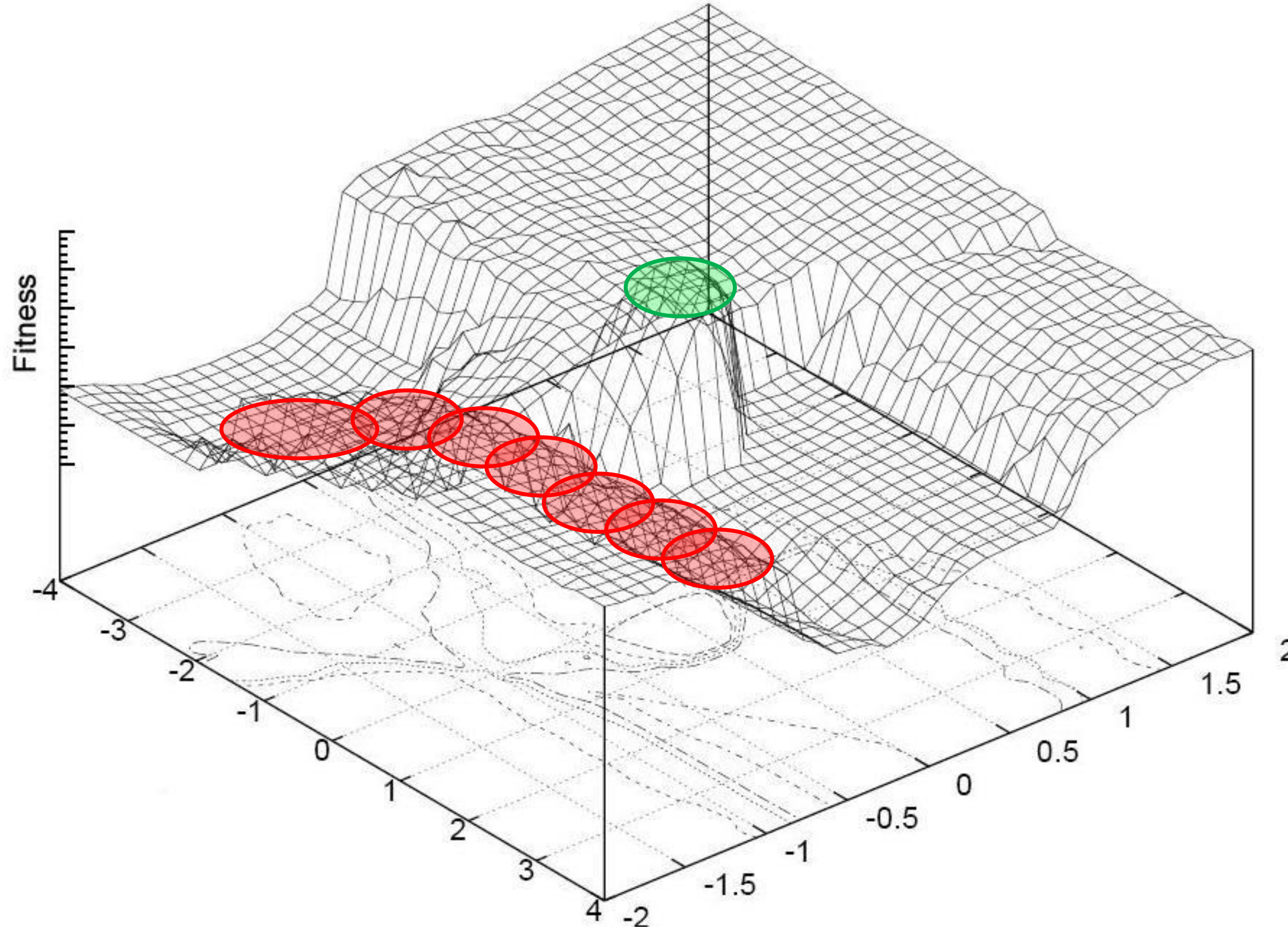
1. "On page 74 the dissertation states, that the evolution time of IEO is significantly lower (by approx. 60 %) than the non-interactive EO, "since without human evaluator it has to explore significantly higher portion of the search space". How is it possible to abandon a part of the search space based on the human evaluation (e.g. in the studied navigation problem)?"

2. "What are the main conceptual differences of the studied situational control and behavior base control?"

Review 2 – Question 1

"On page 74 the dissertation states, that the evolution time of IEO is significantly lower (by approx. 60 %) than the non-interactive EO, "since without human evaluator it has to explore significantly higher portion of the search space". How is it possible to abandon a part of the search space based on the human evaluation (e.g. in the studied navigation problem)?"

"It is clear, that the given (heuristic) function $F_i()$ *does not cover all the criteria (and other runtime statistics) and obviously may lead to individual solutions which differ significantly from the desired goal. For example, the individual may go straight with maximum velocity and then suddenly stop when the length of its trajectory equals the track length l. This is fair in order to optimize* $F_i()$ *but far away from a solution which completes the circuit properly."*

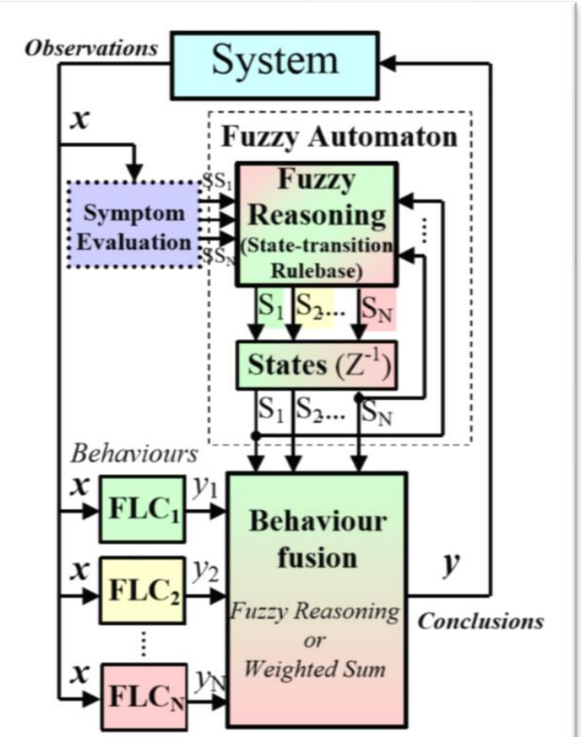

Fitness
-4
-3
-2
-1
0
1
2
3
4
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

Review 2 – Question 2

"What are the main conceptual differences of the studied situational control and behavior base control?"

Situational Control:
- *One* **strategy** per situation
- Strategies may be ***switched*** in different situations

Behavior Base Control:
- *Several* ***behaviors*** fused and applied ***simultaneously*** in any situation



The applied behaviour-based control structure

Related work:
Szilveszter, Kovács. 2003. A Flexible Fuzzy Behaviour-based Control Structure for Adaptive Applications. Available: http://conf.uni-obuda.hu/HUCI2003/Szilveszter.pdf

Questions – Review 3

1. *"How is the intelligent space defined and delimited (for movement stability and quality of control) for movement of a robot within intelligent space?"* ↓
2. *"What is the basis of adaptation of models created using FCM? Describe the algorithm of adaptation."* ↓
3. *"From the solved example and verification it is not possible to declare advantages of the proposed method to conventional approaches. Conventional and proposed solutions are not mutually compared. What quarantees that the selected method is suitable, or even the best? What are quantitative and qualitative criteria to determine "optimality" of the extended FCM method?"* ↓
4. *"Specify what is your main contribution to the development of the scientific field of cybernetics. Is it in the area of methods, in the area of software or in the area of application of new approaches for modeling, control, optimization and prediction of robot movement trajectories?"* ↓
5. *"Were robots Qbo and TurtleBot used in order to verify the FCM method? If it is so, describe the experiments and their results."* ↓
6. *"Is it possible to generalize the results of the dissertation and apply it to optimal planning of operation of industrial robots? What are the conditions for successful and direct application of the developed program system for practical use?"* ↓

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Otázky – Recenzent 3

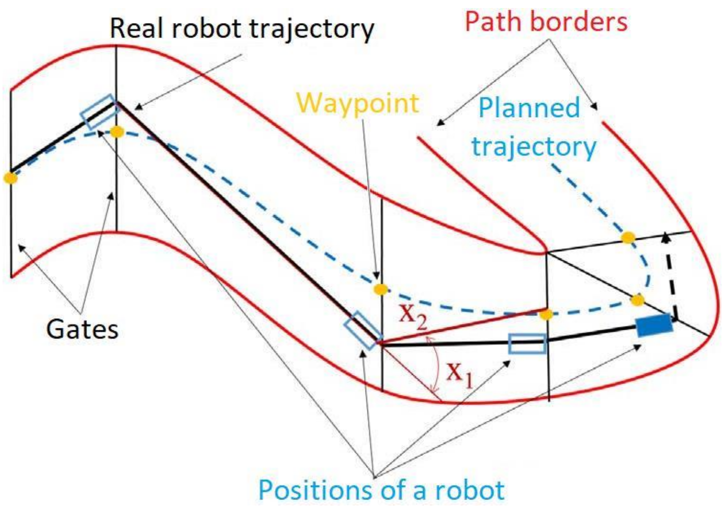
1. „Ako je definovaný a vymedzený inteligentný priestor (stabilita pohybu, kvalita riadenia) pre pohyb robota v inteligentnom priestore ?“↓
2. „V čom spočíva adaptácia modelov vytvorených pomocou FCM ? Opíšte algoritmus adaptácie.“↓
3. „Z riešeného príkladu a overenia nie je možné deklarovať výhody navrhovanej metodiky oproti klasickým prístupom. Konvenčné a navrhované riešenie nie je navzájom porovnané. Čo je zárukou, že vybraná metóda je vhodná resp. najlepšia, aké sú kvalitatívne a kvantitatívne kritéria pre posúdenie „optimálnosti“ rozšírenej metódy FCM?“↓
4. „Špecifikujte v čom spočíva Váš hlavný prínos k rozvoju vedného odboru Kybernetika, je to v oblasti metód, v oblasti SW, metodiky a aplikácie nových prístupov pre modelovanie, riadenie optimalizáciu a predikciu trás pohybu robota ?“↓
5. „Pre overenie metodiky FCM boli testované roboty Qbo a TurtleBot ? Ak áno opíšte experimenty a výsledky experimentov.“↓
6. „Dajú sa výsledky dizertačnej práce zovšeobecniť a aplikovať pre optimálne plánovanie činnosti robotov aj v priemysle ? Aké sú podmienky pre úspešnú a priamu aplikáciu vyvinutého programového systému pre praktické využitie ?“↓

Review 3 – Question 1

„Ako je definovaný a vymedzený inteligentný priestor (stabilita pohybu, kvalita riadenia) pre pohyb robota v inteligentnom priestore ?"

"How is the intelligent space defined and delimited (for movement stability and quality of control) for movement of a robot within intelligent space?"

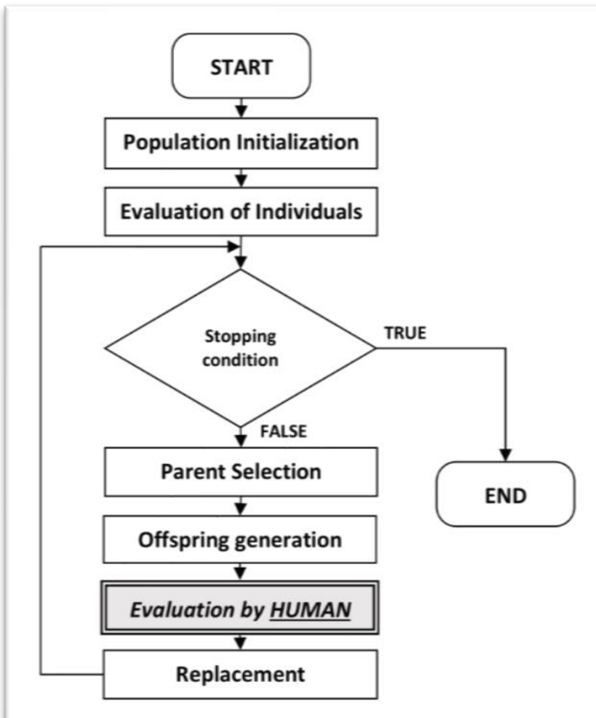
- The space is delimited by its map.
- Robot trajectory is given by path planner.
- Criteria that were considered:
  - C1: relative average absolute angular turning,
  - C2: relative average absolute acceleration,
  - C3: relative trajectory length,
  - C4: relative average speed,
  - C5: relative road passing time,
  - C6: number of sheers (deviations from road borders),
  - C7: success or fail in passing the road (yes or no).



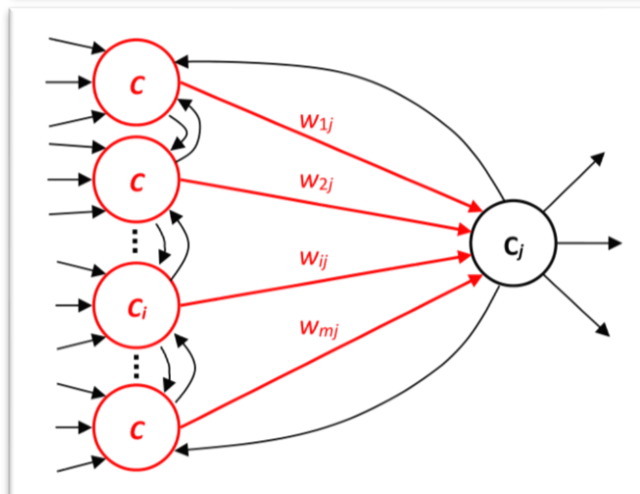
Review 3 – Question 2

„V čom spočíva adaptácia modelov vytvorených pomocou FCM ? Opíšte algoritmus adaptácie.“

“What is the basis of adaptation of models created using FCM? Describe the algorithm of adaptation.”



$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & C_4 & C_5 \end{array} \\ \begin{pmatrix} 0 & 0{,}28 & 0 & 0 & -0{,}13 \\ 0 & 0 & -0{,}35 & 0 & 0 \\ 0 & 0 & 0 & 0{,}45 & 0{,}93 \\ 0 & 0{,}83 & 0 & 0 & 0 \\ -0{,}18 & 0 & 0 & -0{,}67 & 0 \end{pmatrix} \end{array}$$



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Review 3 – Question 3

„Z riešeného príkladu a overenia nie je možné deklarovať výhody navrhovanej metodiky oproti klasickým prístupom. Konvenčné a navrhované riešenie nie je navzájom porovnané. Čo je zárukou, že vybraná metóda je vhodná resp. najlepšia, aké sú kvalitatívne a kvantitatívne kritéria pre posúdenie „optimálnosti“ rozšírenej metódy FCM?“

“From the solved example and verification it is not possible to declare advantages of the proposed method to conventional approaches. Conventional and proposed solutions are not mutually compared. What quarantees that the selected method is suitable, or even the best? What are quantitative and qualitative criteria to determine “optimality” of the extended FCM method?”

- Examination and comparison of conventional (traditional) methods of control was not stated as a goal of the work. It has been done in previous works:

Tab. 1 Qualitative comparison of AI methods [28].

	FS	ANN	EA	CT	SAI
Mathematical model	2	4	4	1	3
Learning capability	4	1	2	4	4
Knowledge representation	1	4	3	3	1
Expert knowledge	1	4	4	3	1
Nonlinearity	1	1	1	4	3
Optimization ability	4	2	1	3	4
Fault tolerance	1	1	1	4	4
Uncertainty tolerance	1	1	1	4	4
Real-time operation	1	2	3	1	4

Legend: FS – fuzzy systems, ANN – artificial neural networks, EA – evolutionary algorithms, CT – conventional control theory, SAI – symbolic artificial intelligence. Lower score is better.

Related work:
Lin, C.-T. , Lee, C. S. G. 1996. "Neural Fuzzy Systems: A Neuro-Fuzzy Synergism to Intelligent Systems," Prentice-Hall PTR.

- In our work, we have examined only the well established means of CI, mostly FCM:
  - TTR FCMs have simplified the design process for the expert.
  - Semi-interactive evolution of FCMs have improved the efficiency of adaptation:

Tab. 6 Relative comparison of results of all IEO methods [64].

Adaptation Method:	Non-Interactive	Semi-Interactive	Full-Interactive
Program runtime:	1	0,577459124	0,86169313
Evolution time:	1	0,428788467	0,386065932
Waiting for user:	0	0,309849687	1
Interaction time:	0	0,313896941	1
Num. of generations:	1	0,852941176	0,705882353
Generated individuals:	1	0,85915493	0,718309859
Best fitness:	0,381818923	1	0,783865877
Interaction interval:	Disabled	Every 10 generations	Every 1 generation

Contribution (according to the 1st Goal):
Puheim, M., Vaščák, J. 2017. "Semi-Interactive Population-Based Optimization of Fuzzy Cognitive Maps". Unpublished work in progress.

Review 3 – Question 4

„Špecifikujte v čom spočíva Váš hlavný prínos k rozvoju vedného odboru Kybernetika, je to v oblasti metód, v oblasti SW, metodiky a aplikácie nových prístupov pre modelovanie, riadenie optimalizáciu a predikciu trás pohybu robota ?“

“Specify what is your main contribution to the development of the scientific field of cybernetics. Is it in the area of methods, in the area of software or in the area of application of new approaches for modeling, control, optimization and prediction of robot movement trajectories?”

Main contributions were stated in the conclusion of the presentation, here: ↓

Most important scientific contribution:

- FCM adaptation by introducing (semi-)**interactive evolutionary optimization**

Most important technological contribution:

- Creation of **software tools** which simplify and streamline **FCM design** and application in networking environment.

Review 3 – Question 5

„Pre overenie metodiky FCM boli testované roboty Qbo a TurtleBot ? Ak áno opíšte experimenty a výsledky experimentov."

"Were robots Qbo and TurtleBot used in order to verify the FCM method? If it is so, describe the experiments and their results."

- Technologically, this work has dealt with creation of universal networking API and its testing and application in a simulated model of an intelligent space.
- Experiment with physical robots were not part of this work. These have been done in other works:

Related works:
Hvizdoš, J. 2018. "Ubiquitous Robotics in Intelligent Space: New Approaches in Navigation of Ubiquitous Robots." PhD Thesis. Košice, FEEI, DCAI, TUKE.

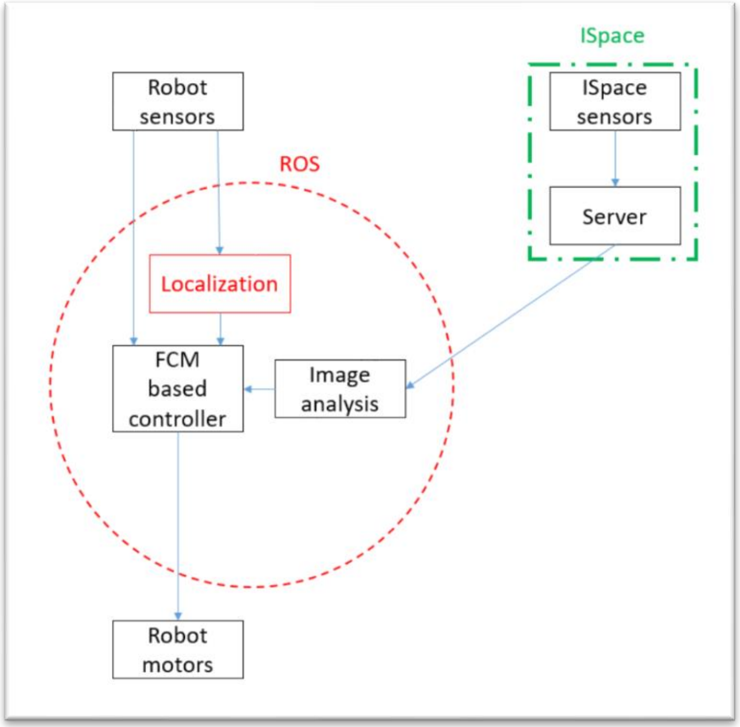


Table 10 – Navigation comparison

Trajectory type	Length	Navigation type	Time taken
Straight line	3m	Teleoperation	9.5s
Straight line	3m	FCM controller	6.9s
Single curve	4m	Teleoperation	15.0s
Single curve	4m	FCM controller	14.8s
Simple path	4m	Teleoperation	12.6s
Simple path	4m	FCM controller	10.3s
Complex path	5m	Teleoperation	24.6s
Complex path	5m	FCM controller	18.5s

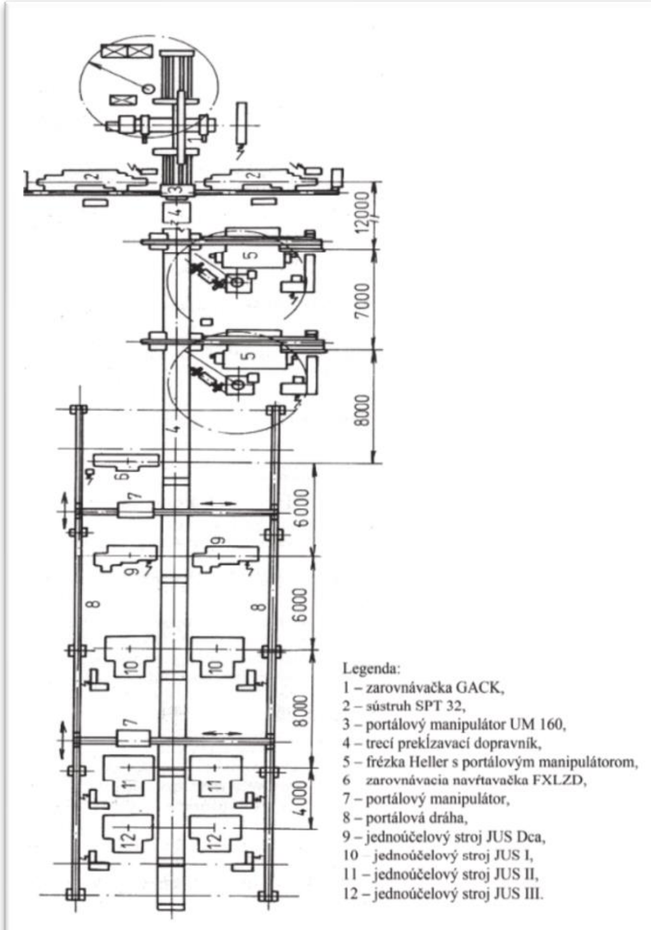
Source: Hvizdoš, J. 2018. "Ubiquitous Robotics in Intelligent Space: New Approaches in Navigation of Ubiquitous Robots." PhD Thesis. Košice, FEEI, DCAI, TUKE.

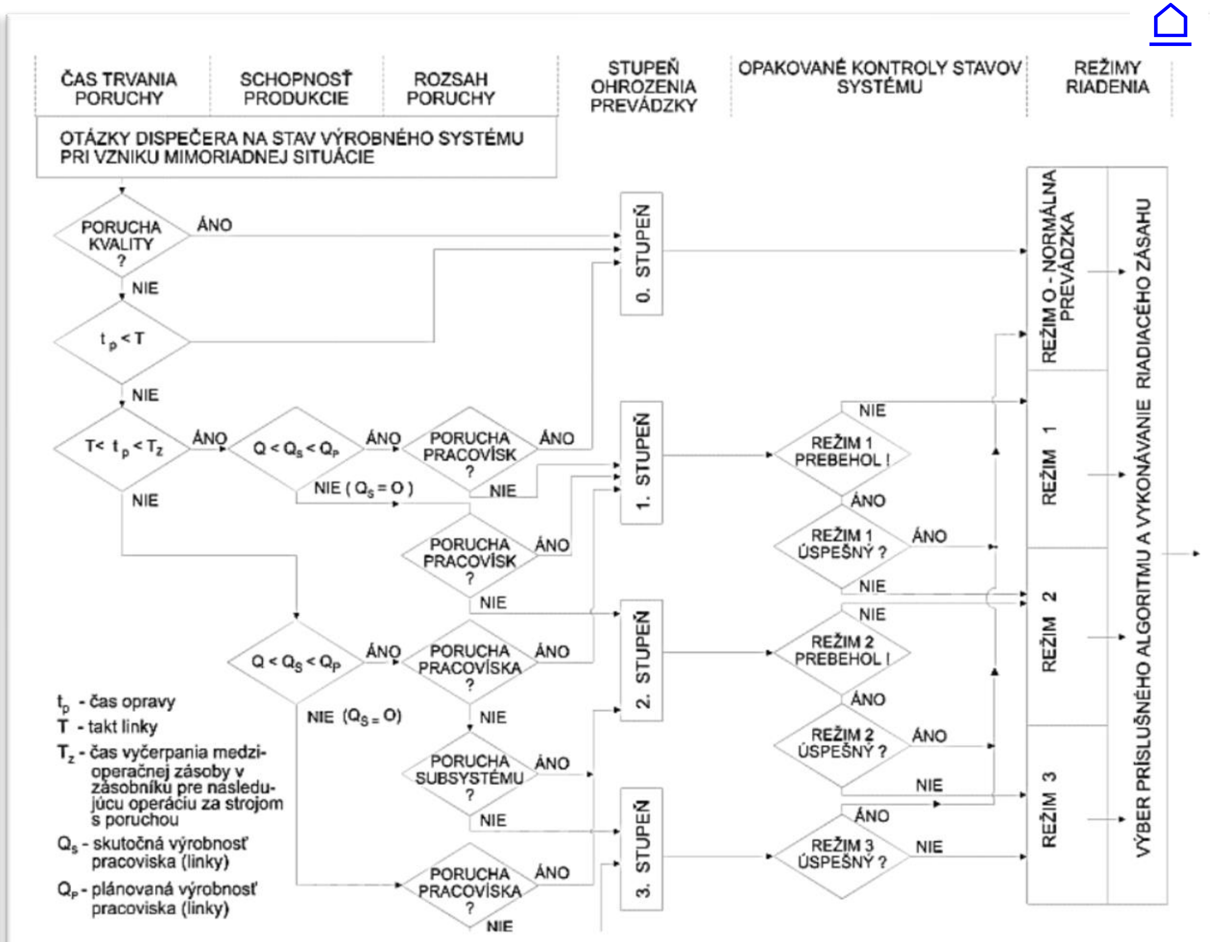
Review 3 – Question 6

„Dajú sa výsledky dizertačnej práce zovšeobecniť a aplikovať pre optimálne plánovanie činnosti robotov aj v priemysle ? Aké sú podmienky pre úspešnú a priamu aplikáciu vyvinutého programového systému pre praktické využitie ?“

“Is it possible to generalize the results of the dissertation and apply it to optimal planning of operation of industrial robots? What are the conditions for successful and direct application of the developed program system for practical use?”

- The overall proposal for Situational Control of Intelligent space as described in the work is applicable to the Intelligent space at Center for Intelligent Technologies
- Situational Control has already been applied in industrial production and control of robotized assembly lines.
- Proposed Python Open Fuzzy Cognitive Maps Library has been created as a general tool applicable to any suitable application.
- Proposed control strategy for navigation of a mobile robot may be applied to any mobile robot in any intelligent space after modifications related to a specific robot and a specific workspace.

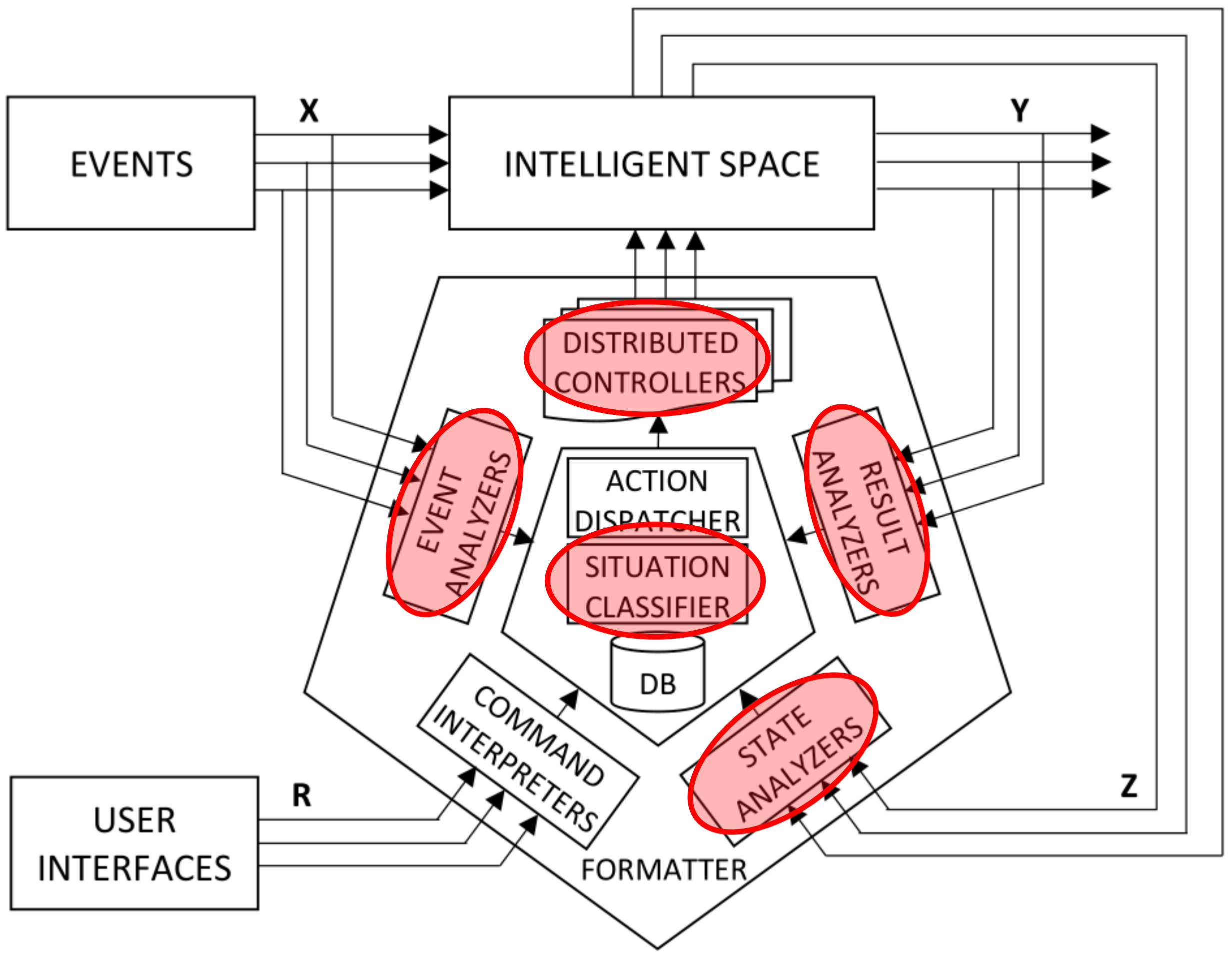




Related works:

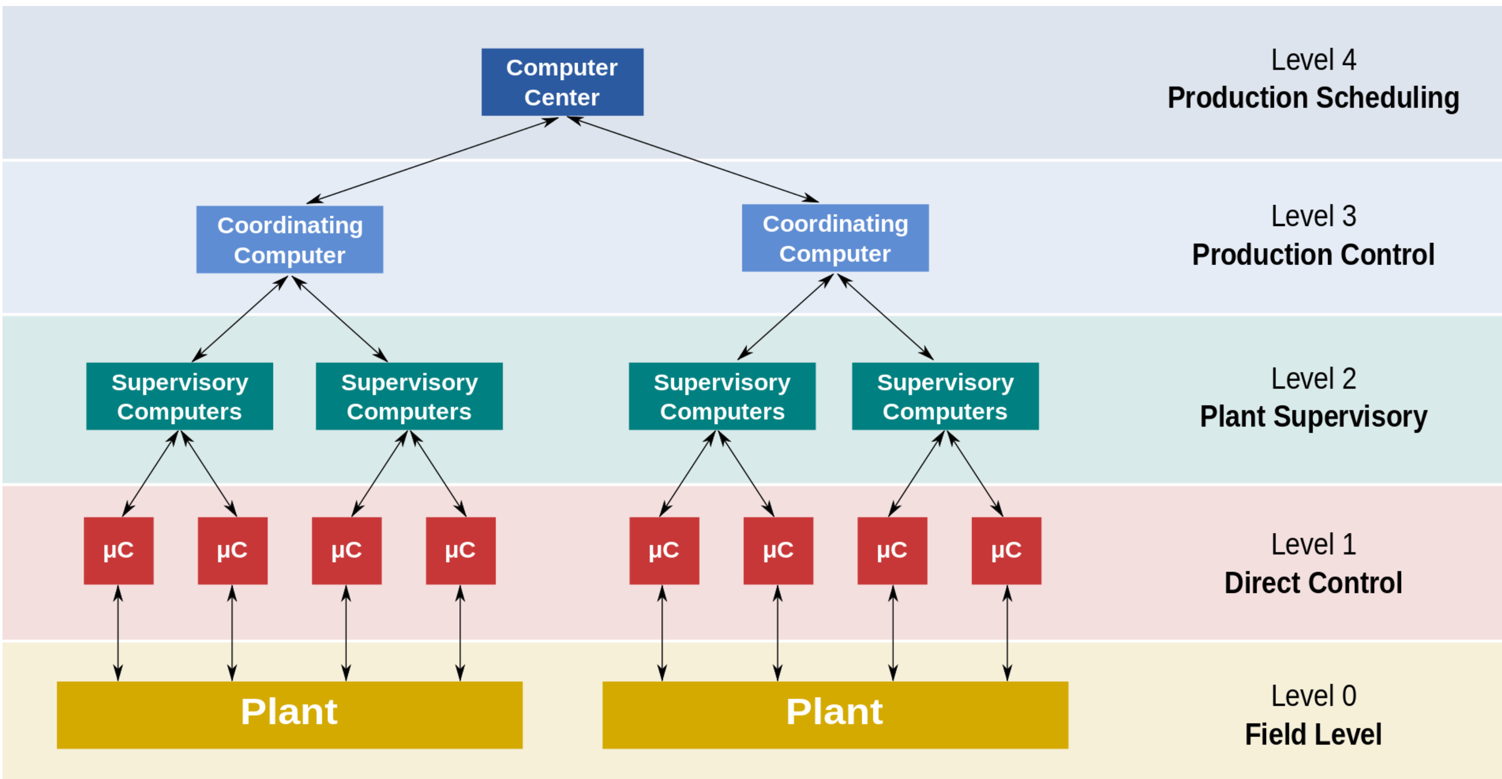
- Madarász, L., „Základné princípy situačného riadenia a formalizácie rozhodovacích procesov pri riadení zložitých hierarchických systémov.“ Kandidátska dizertačná práca, pp. 95, EF VŠT Košice, 1982.
- Madarász, L., Šimšík, D., 1988. Application of Expert Systems in the Situational Control of Robotic Technological Complexes. System Sci-ence, Vol. 14, No. 2, Wroclaw, pp. 87-96
- Sarnovský, J., a kol., 1992. Riadenie zložitých systémov. Alfa Bratislava, ISBN 80-05-00945-3, 384 pp.

- Proposed *Python Open Fuzzy Cognitive Maps Library* has been created as a general tool applicable to any suitable application.



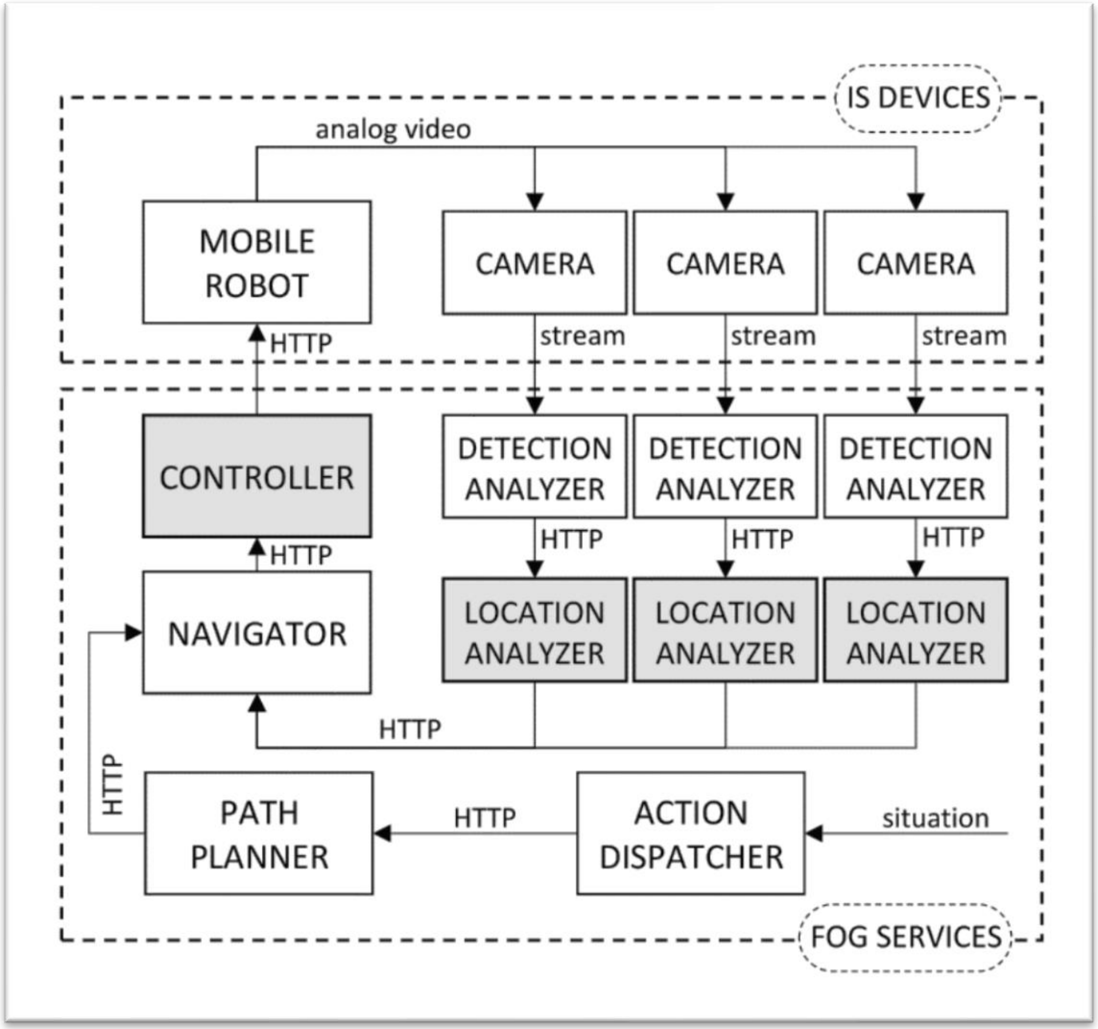
Requirements for successful utilization of PyOpenFCM in industrial applications:

- Supervisory Control and Data Acquisition (SCADA) system
- Information processing system with compatible HTTP API
- Compatible HMI (Human Machine Interface)
- Plant model for generation of training data for machine learning



Functional levels of a manufacturing control operation

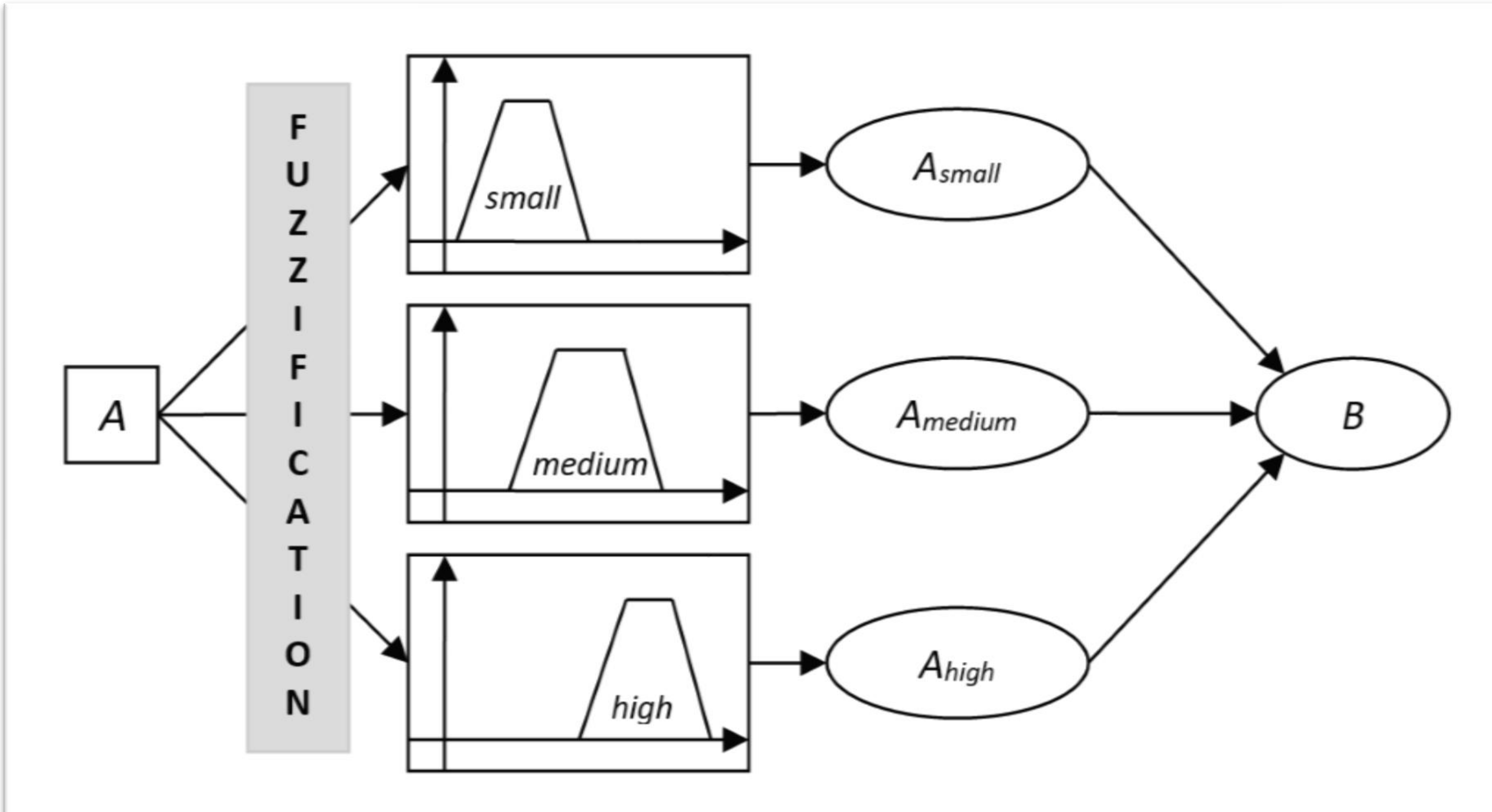
- Proposed control strategy for navigation of a mobile robot may be applied to any mobile robot in any intelligent space after modifications related to a specific robot and a specific workspace.



Discussion - Various

1. FCMs and linguistic variables ⤓
2. Properties of complex systems & Intelligent spaces ⤓
3. Difference between FCMs and ANNs ⤓
4. Time window & Three-Term Relations ⤓
5. State-of-art of Intelligent Spaces ⤓
6. Situational Control Application ⤓

FCMs and linguistic variables



Properties of complex systems & Intelligent spaces

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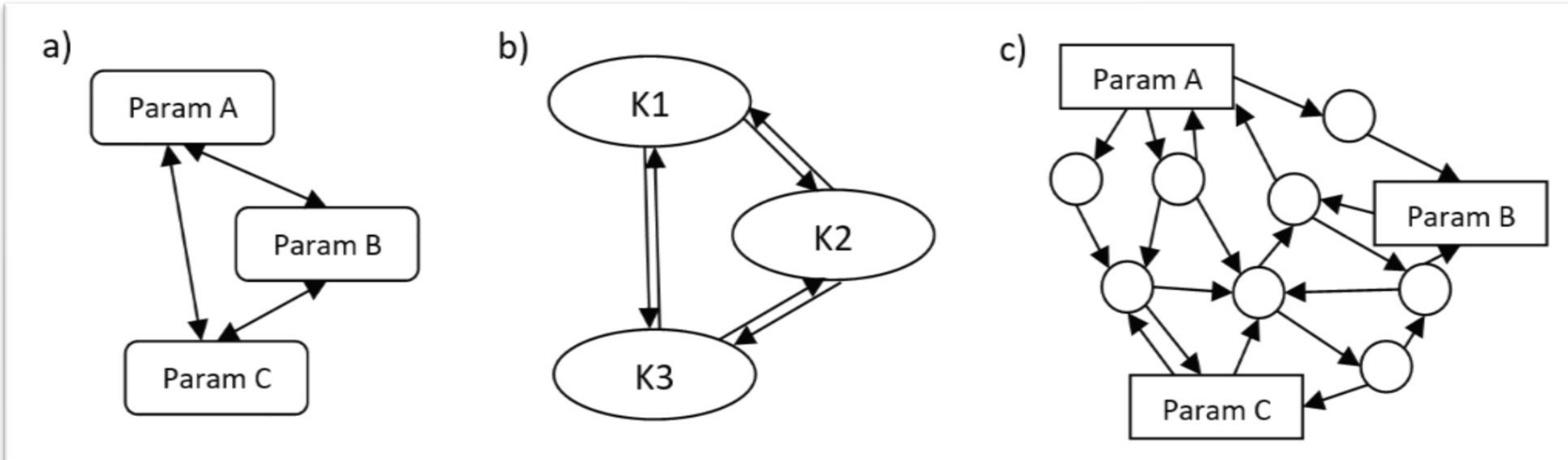
Complex System (CS)	Intelligent Space (IS)
• a *large number of elements* which number can increase or decrease,	• a *large number of IoT devices* which can be added or removed accordingly,
• *relationships between the elements* defining the structure of the CS may change,	• *mutual communication between IoT devices* may change according to the specific use case of the IS,
• *hierarchy of the organizational structure* of the components of the CS (regardless of whether it is a management or controlled system),	• *hierarchy of networking components* of the IS corresponding to different layers of ISO/OSI model, hierarchical utilization of cloud/fog/edge computing paradigms,
• *autonomous decision-making of elements* (decentralized organization of the CS, where individual elements have large degree of autonomy),	• *independent IoT devices* (decentralized sensors, actuators and other devices, integration of edge computing into devices),
• *change of space* (dimension of space) in which the CS is located and in which it operates,	• *change of space disposition* (objects within the space), relocation of sensors, actuators and other equipment,
• *change in the organizational structure* of the CS (i.e. changing links or relationships between elements of the CS).	• *change of networking technologies and communication protocols*, reassignment of devices to other subnets.

Difference between FCMs and ANNs



FCM

- Managing dynamic phenomena thanks to a feedback structure.
- Lower accuracy of the model (due to linear relationships between concepts).
- Better adaptation to changed conditions.
- Better readability of the model.
- Possibility to derive basic rules of system behavior.
- More difficult learning.
- More complicated implementation.

FF ANN

- No feedback.
- The need for higher accuracy of the model.
- Problem with adapting to changed conditions.
- Low readability of the model.
- Simpler learning.
- Simple implementation.

Time window & Three-Term Relations

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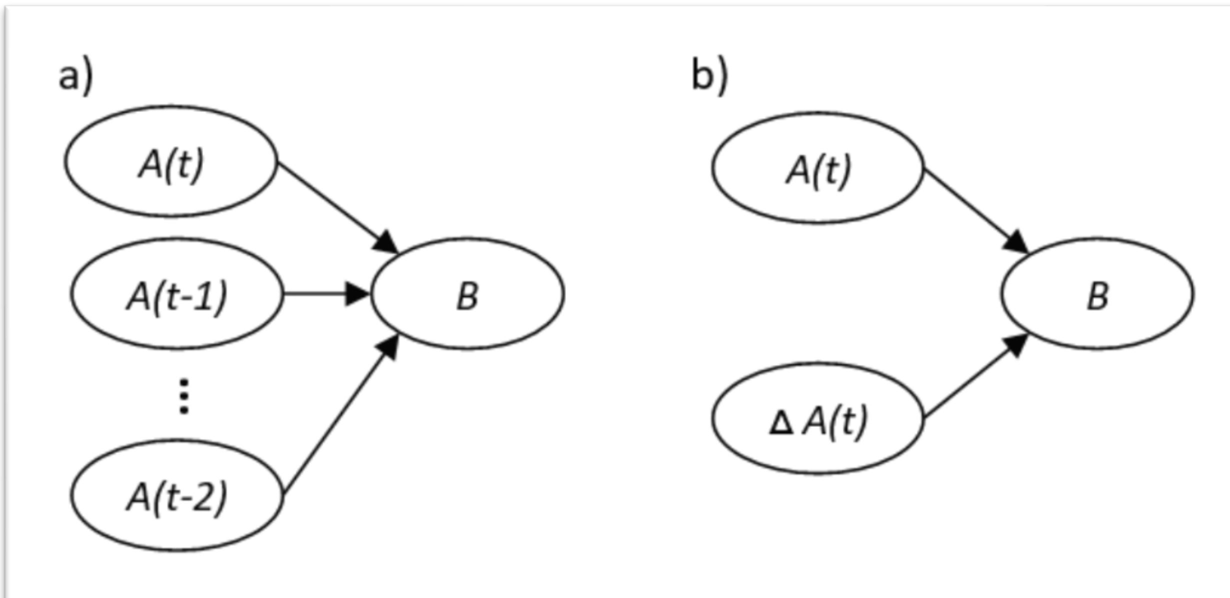
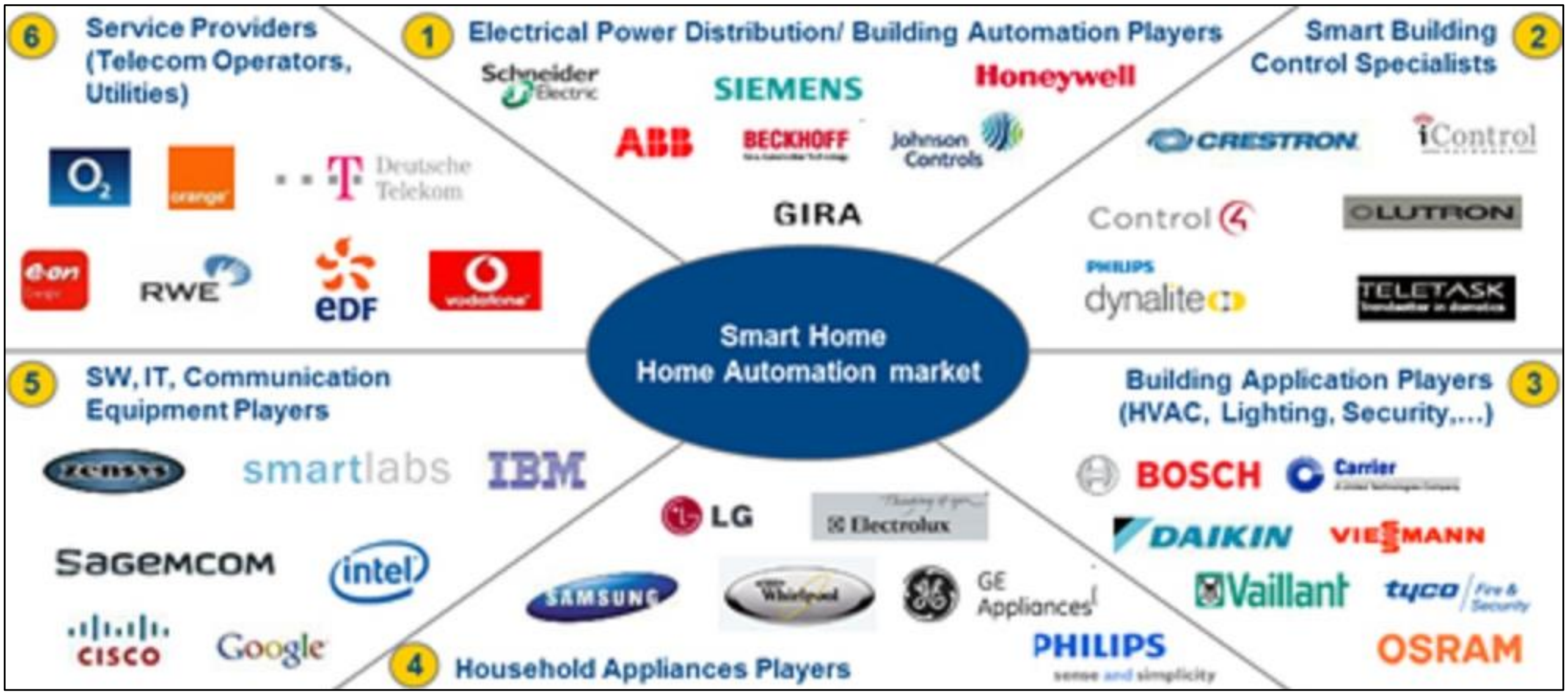


State-of-art of Intelligent Spaces

State-of-art of Intelligent Spaces



Related works:

- Kouba, A., Shakshuki, E. 2016. Robots and Sensor Clouds. In: Studies in Systems, Decision and Control. Vol 36. Num. 1. pp. 94. Springer International Publishing. ISBN 978-3-319-22167-0

Situational Control Application

Initial planning phase and implementation of situational control:

1. Description of the controlled system.
2. Setting of global control objectives.
3. Proposal of situational classes (frames).
4. Description of control strategies assigned to each situational class.
5. Algorithmization of individual control strategies.
6. Implementation.

The system is put into operation and managed in an operational control phase:

7. Classification to the appropriate class of situations (using situation classifier).
8. Choice of a corresponding control strategy (using action dispatcher).
9. Realization of particular control functions (using one or more selected controllers).

Related works:

- Madarász, L., „Základné princípy situačného riadenia a formalizácie rozhodovacích procesov pri riadení zložitých hierarchických systémov.“ Kandidátska dizertačná práca, pp. 95, EF VŠT Košice, 1982.
- Madarász, L., Vaščák, J., Andoga, R., Karoľ, T. 2010. “Rozhodovanie, zložitosť a neurčitosť,“ pp. 396, Elfa s.r.o. Košice. ISBN 978-80-8086-142-1.