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## Autonomic Management of Large- Scale Critical Infrastructures

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# Outline

- Multiple policy optimisation in large-scale decentralized systems
- Reinforcement Learning (RL) approach to autonomic management
- First Results
- Future Work



# Optimisation in large-scale decentralized systems

- Optimisation w.r.t. multiple conflicting system policies
  - Different priority of policies
  - Different spatial scope of policies: local, global, regional and different temporal scope of policies: continuous, sporadic
- Coordination of multiple agents
  - Adapting to changing operating conditions
  - Variety of local sensor information available, but no global view
- Need for autonomic decentralized management
- Example application area: Urban Traffic Control (UTC)
- Possible application to management of other large-scale critical infrastructures – gas, water, electricity supply

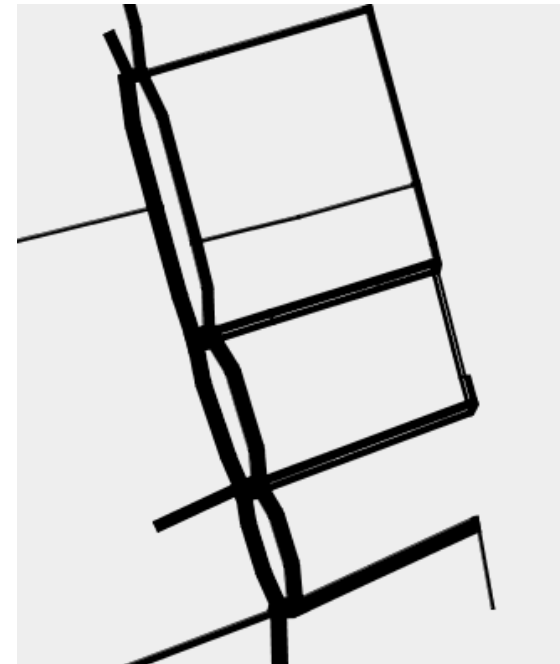


# Self-Organising Techniques

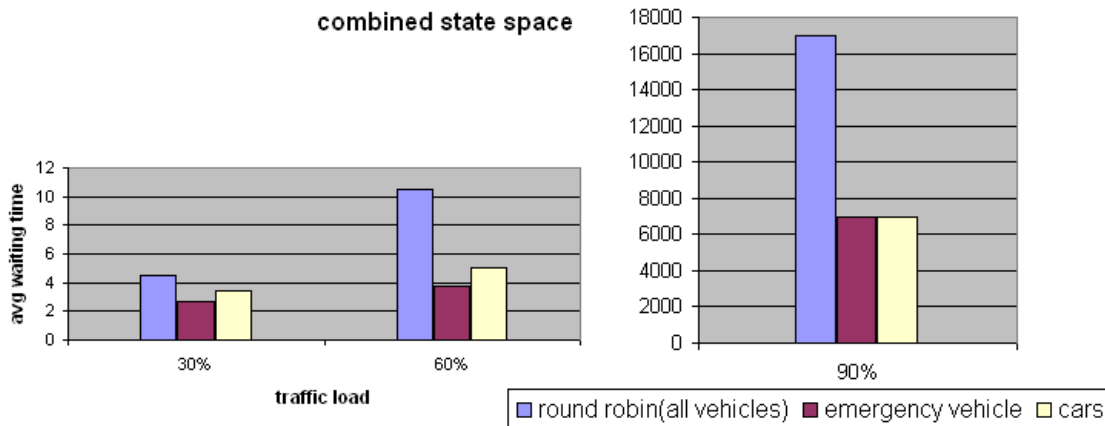
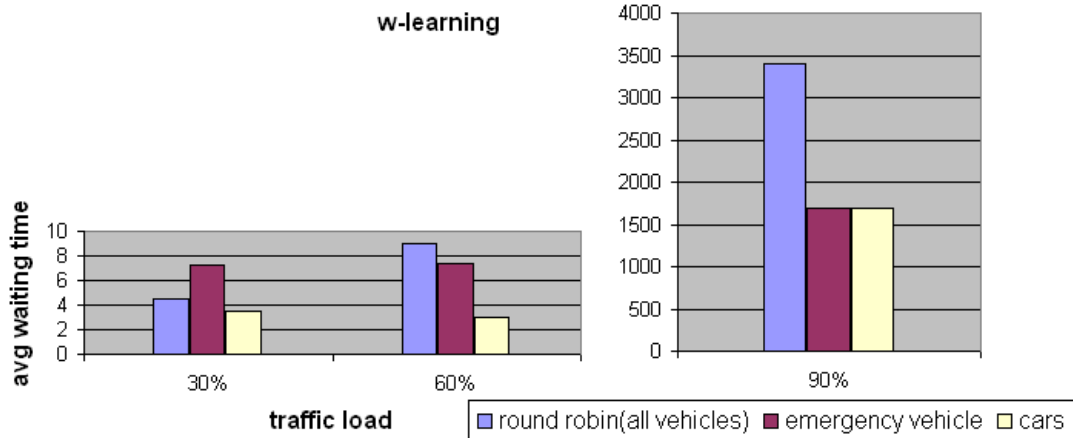
- Decentralized learning and cooperation
  - Ant colony optimization, particle swarms, evolutionary computing
- Reinforcement Learning (RL)
  - Single agent, single policy [1]
  - Applications in autonomic computing – e.g. dynamic resource allocation [5]
- Collaborative Reinforcement Learning (CRL) [2]
  - Multiple agents, single policy
  - Agents collaborate by exchanging feedback on each other's actions
- W-Learning [3] – multiple policies, single agent
  - Policies compete for the control of the agent actuator
- Combined state spaces [4] - multiple policies, single agent
  - Policies are combined into a single learning process

# First Results

- Single agent, multiple policies:
  - Prioritize emergency vehicles (high priority, regional, sporadic policy) vs maximise vehicle throughput (low priority, global, continuous policy)
  - RL techniques- W-Learning, Combined state space
- Multiple agents, single policy
  - 5 junctions from Dublin city map
- Compared with round robin



# First Results





# First Results - Conclusions

- Single junction, multiple policies
  - Combined state space more suitable for this combination of policies
    - shows better improvement over round robin than W-learning
    - Clearly prioritizes higher priority policy, unlike W-learning
  - W-learning possibly more suitable for policies with similar characteristics
  - High dependency between policies – prioritizing for cars improves ambulance performance
- Multiple junctions, single policy
  - no communication/coordination between agents
  - results confirm single junction results

# Future Work

- Introduce agents collaboration
- Conduct large-scale experiments on Dublin road map



- Determine relationship between performance of existing techniques (CRL, W-learning, combined state space) and characteristics of policies implemented
- Develop new techniques and/or modify existing ones to improve performance of multiple policy optimisation

# References

- [1] R. S. Sutton and A. G. Barto. *Reinforcement Learning: An Introduction*. A Bradford Book. The MIT Press, Cambridge, Massachusetts, 2002.
- [2] J. Dowling. *The Decentralised Coordination of Self-Adaptive Components for Autonomic Distributed Systems*. PhD thesis, Trinity College Dublin, 2005.
- [3] M. Humphrys. *Action Selection methods using Reinforcement Learning*. PhD thesis, University of Cambridge, 1997.
- [4] H. Cuayáhuitl, S. Renals, O. Lemon, and H. Shimodaira. Learning multi-goal dialogue strategies using reinforcement learning with reduced state-action spaces. In *Proc. of Interspeech-ICSLP 2006*, 2006.
- [5] G. Tesauro. Reinforcement learning in autonomic computing: A manifesto and case studies. *IEEE Internet Computing*, 11(1):22–30, 2007.



# Thank You!

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