Final results from the SPP1183 project

„Marching Pixels Algorithms (1st phase) and Generic Architectures for Emergent Marching Pixels Algorithms (2nd phase)“

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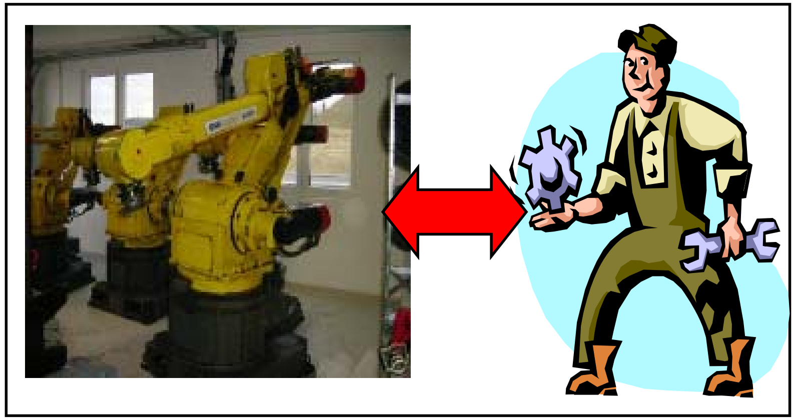
Content

- Motivation
- Engineering Marching Pixels Algorithms
  - Toolbox of Marching Pixels Algorithms
- Hardware Realisations for Emergent Algorithms
  - Application-specific and programmable solutions
  - Distributed fault-tolerance schemes
- Evolving Marching Pixels Algorithms
  - Creature exploration problem
  - Evolving single and multi agent systems
- Summary

Motivation

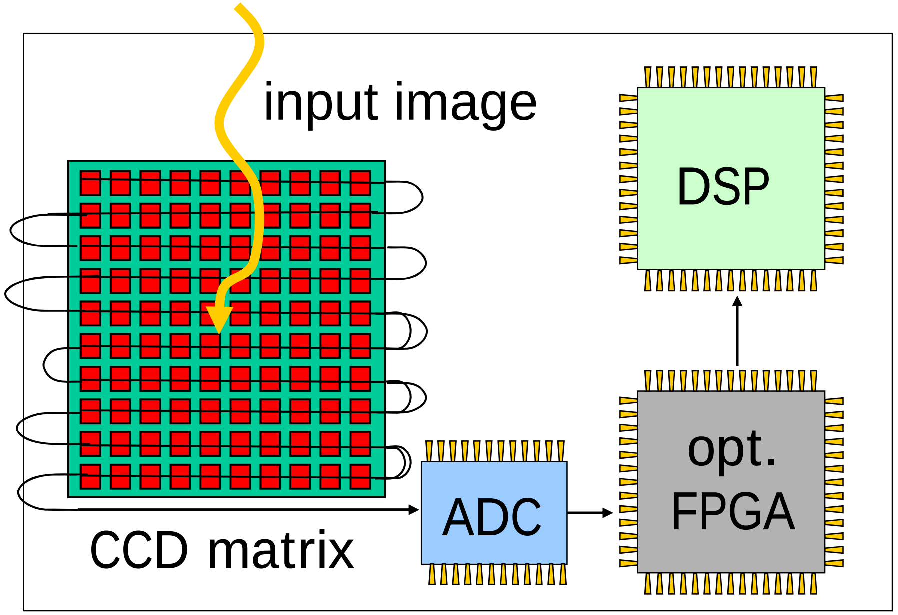
- Co-operation robot ↔ human



- Requirements to CMOS sensor chip
  - Compact
    - fit into small gripper arms
  - Intelligent
    - Autonomous robots
  - Fast
    - Real-time requirements

Motivation

- Current sensor architectures: **serial processing**
  - bottleneck to fulfill response times in *ms* range in robotics



  - Simple estimation: 100 MHz clock, 10 ms response time, Mega pixel resolution → 10 ns time to process one pixel
  - → parallel solutions are necessary

Motivation

- Aim: detect objects and their attributes
  - **Area, centre point and rotation**
- State-of-the-art: High-speed cameras
  - Using high-speed microcontrollers or DSPs
  - Causes high costs
  - Processing single object
- Better solution: a fully parallel (organic) approach
  - Cost-effective solutions
  - Processing more than only one object simultaneously

Marching Pixels Approach

- Marching Pixels – An Organic Computing approach

Swarm of virtual organic units or primitive agents

↓

operate according to local rules

↓

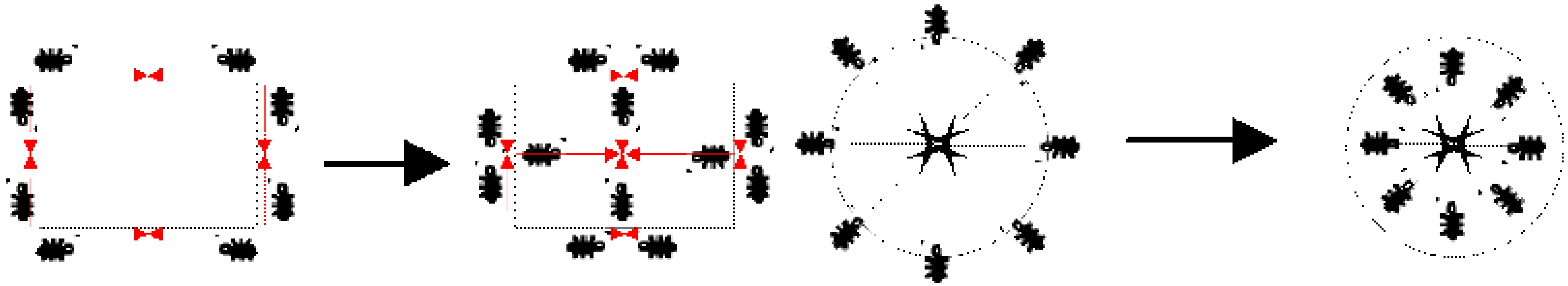
produce emergent behaviour in the global system

Engineered MP Algorithms

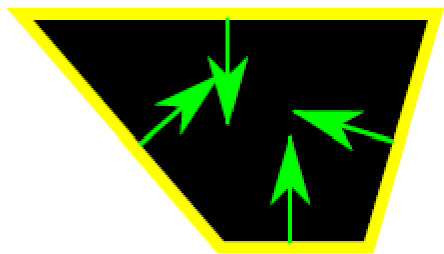
- Toolbox of Marching Pixels (MP) Algorithms
  - For different complex formed objects
    - Convex objects
    - Concave objects
    - Concave interlaced objects
  - Different MP algorithms
    - Functional power and
    - Cost for realisation
  - More effectivity
    - Path planning with MP

Engineered MP Algorithms

- 1st approach: Edge Run algorithm
  - Running along edges and at meeting point join and turn



  - Situation where edge run fails



D. Fey

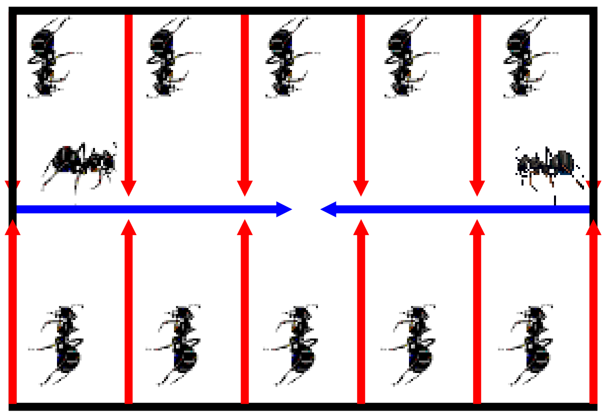
SPP „Organic computing"

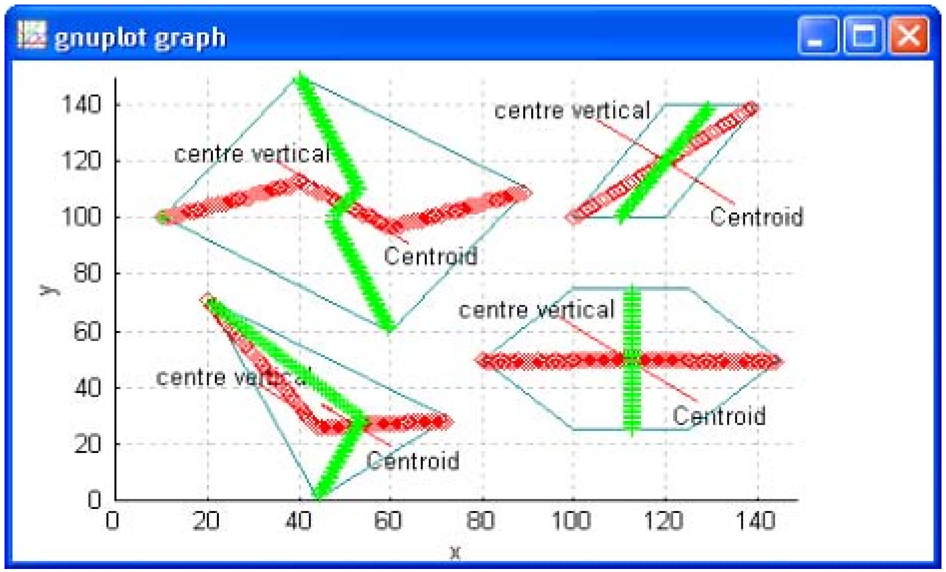
„Final results of the Marching-Pixels project"

22.9.2009, Augsburg

Engineered MP Algorithms

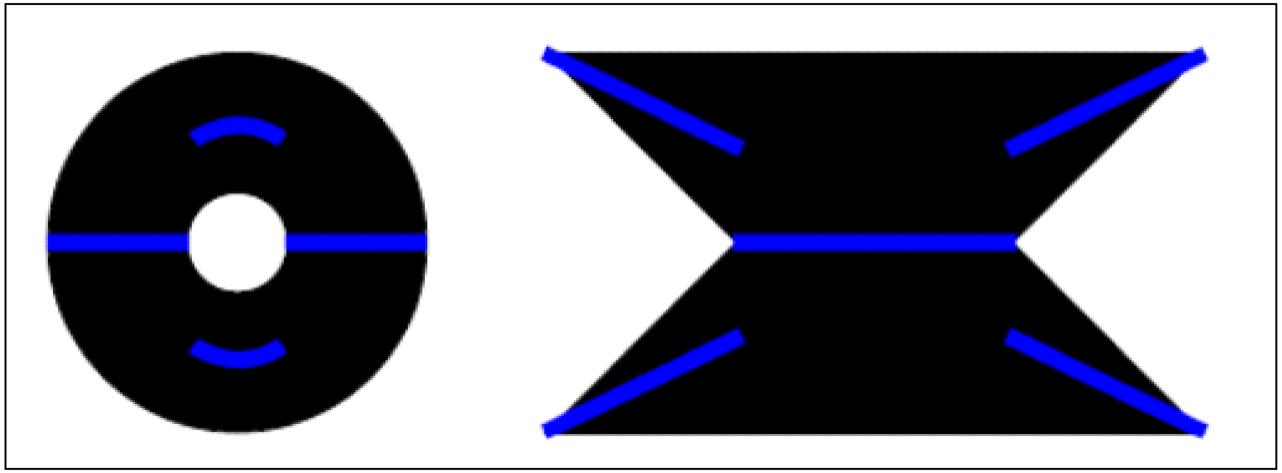
- 2nd approach: Reduction lines
  - Let MPs run to specific points in the object's centre





Engineered MP Algorithms

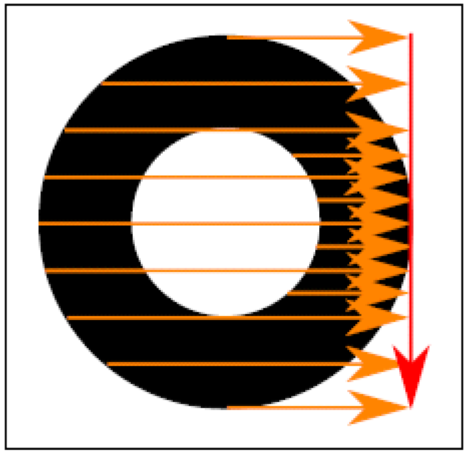
- 2^{nd} approach: Reduction lines
  - Situation where simple centred reduction lines fails

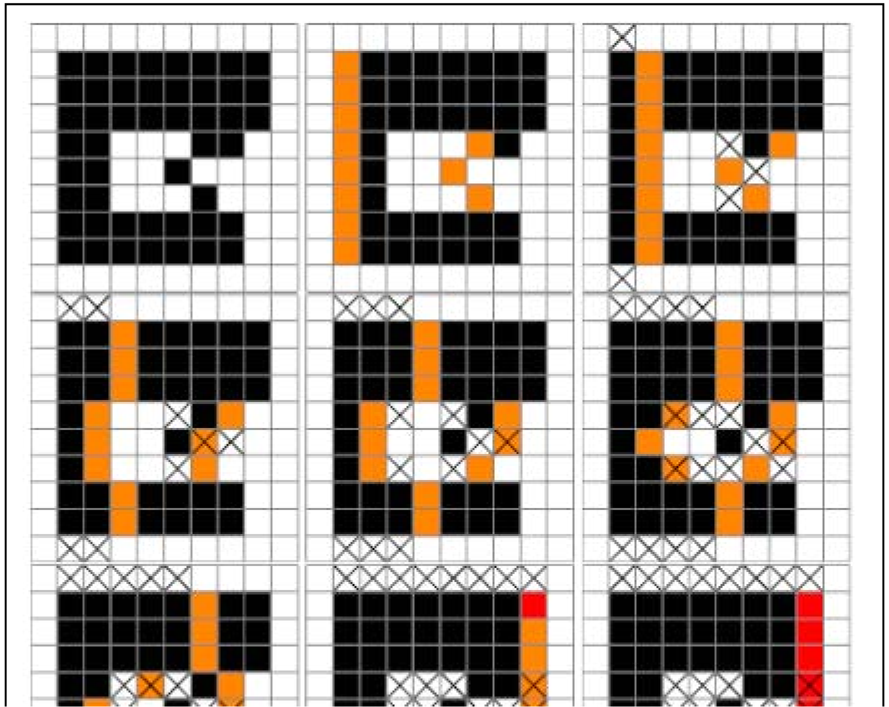


  - In principle solvable with so-called gap-hop

Engineered MP Algorithms

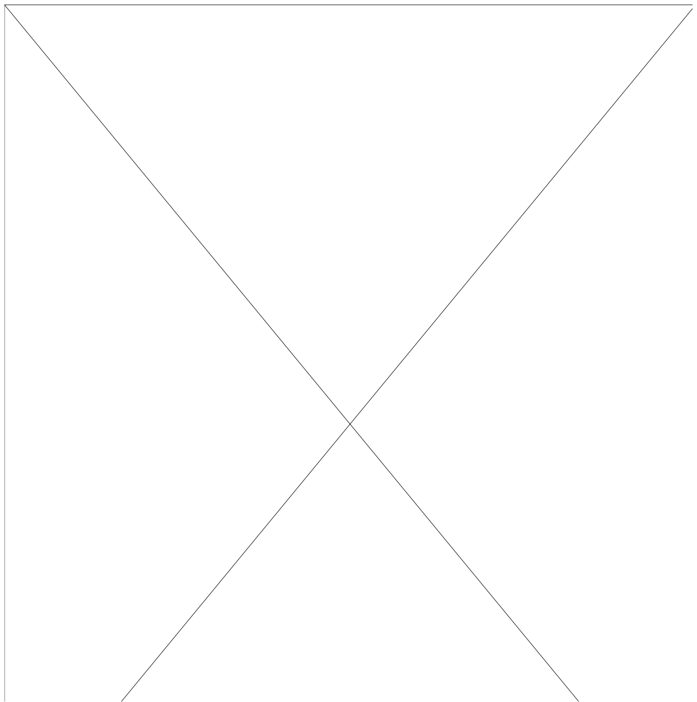
- 3^{rd} approach: Flooding
  - Let MPs flood the object from left to right





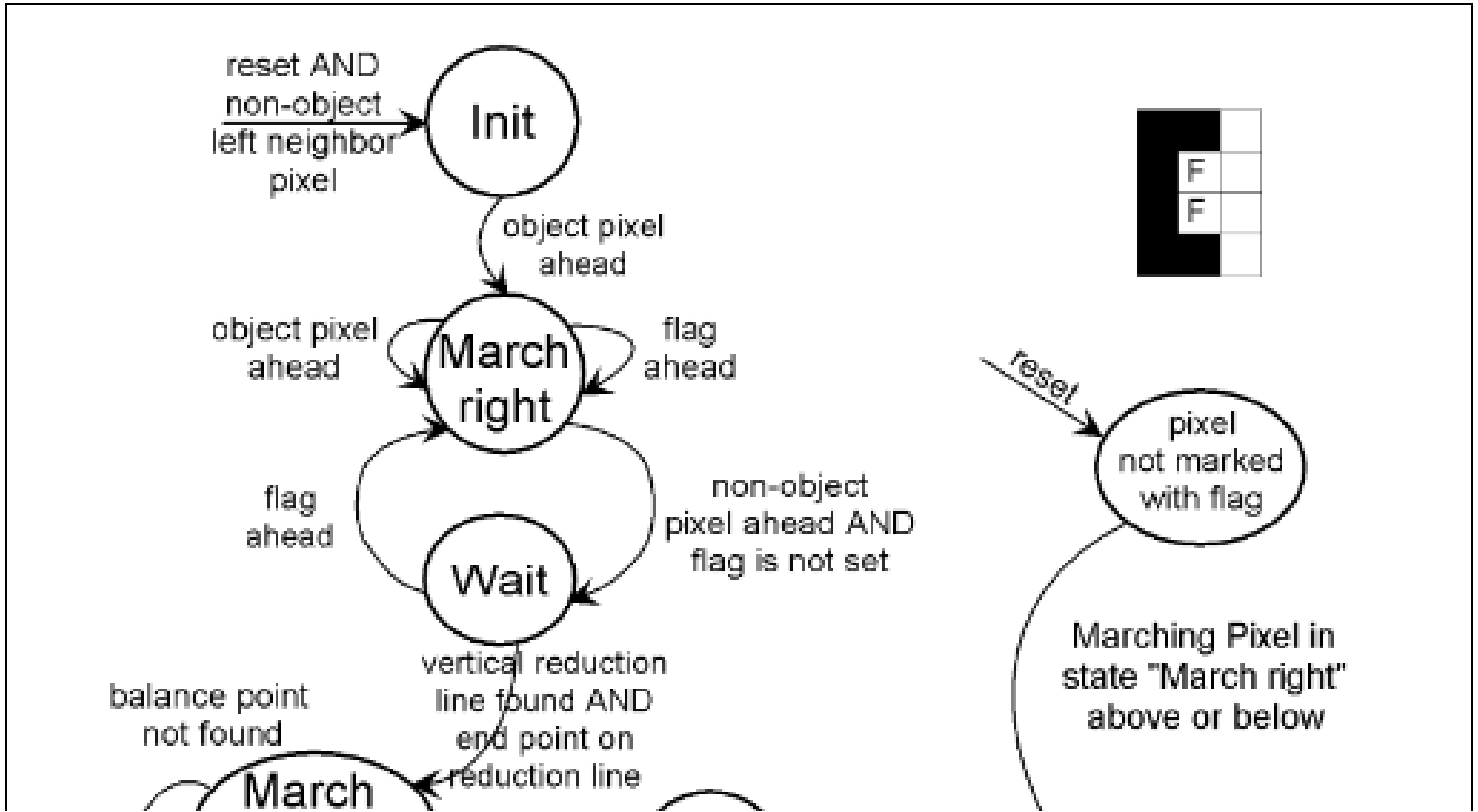
Engineered MP Algorithms

- 3rd approach: Flooding
  - Simulation of flooding



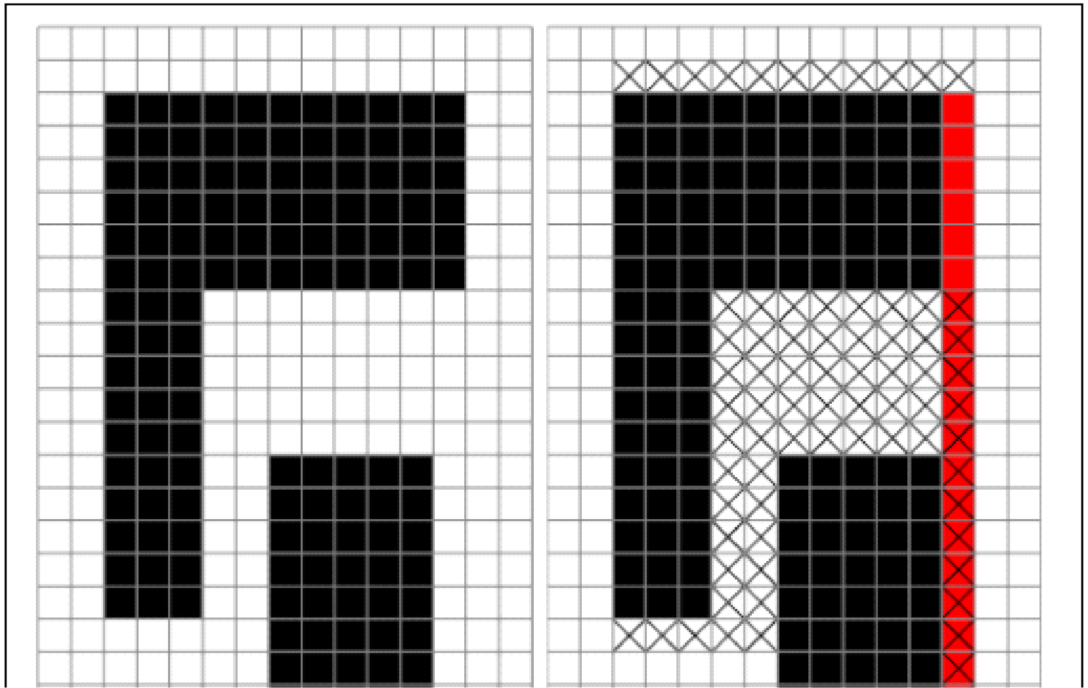
Engineered MP Algorithms

- Designing appropriate Cellular Automata for steering MPs' propagation



Engineered MP Algorithms

- 3^{rd} approach: Flooding
  - Situation where flooding fails
  - If the enveloping rectangulars intersect

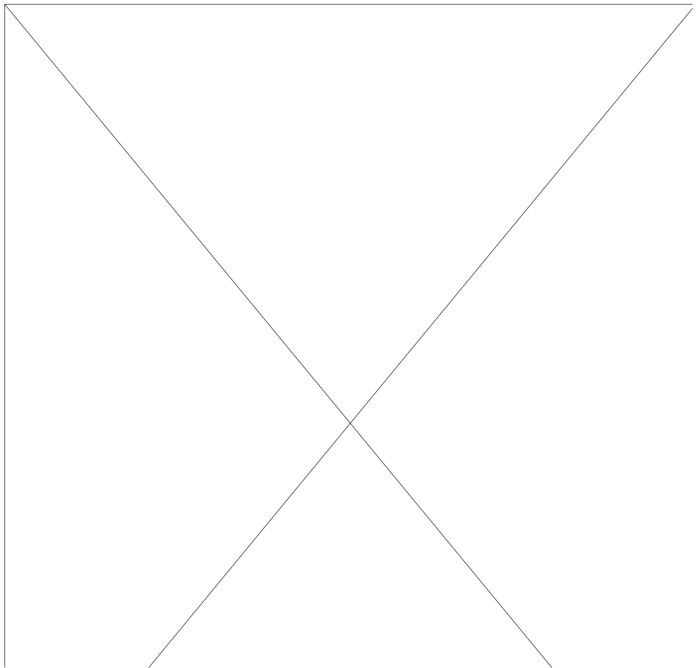


Engineered MP Algorithms

- 4^{th} approach: Opposite Flooding
  - Let MPs flood the object from left to right and from right to left at the same time
  - Opposite wave operates as a kind of barrier

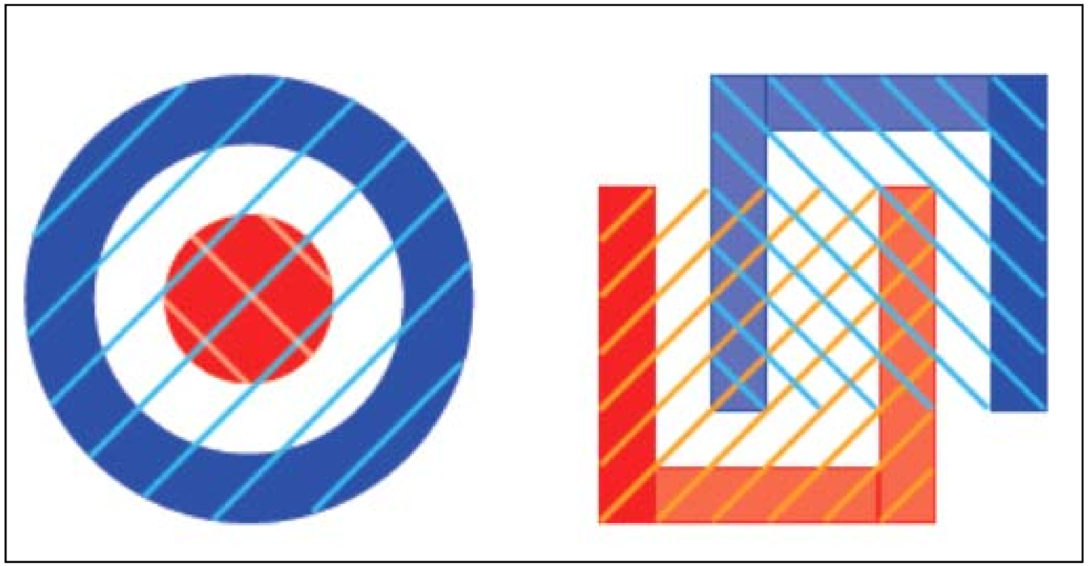
Engineered MP Algorithms

- 4^{th} approach: Opposite Flooding
  - Handles most parallel concave objects
  - More robustness by redundancy possible



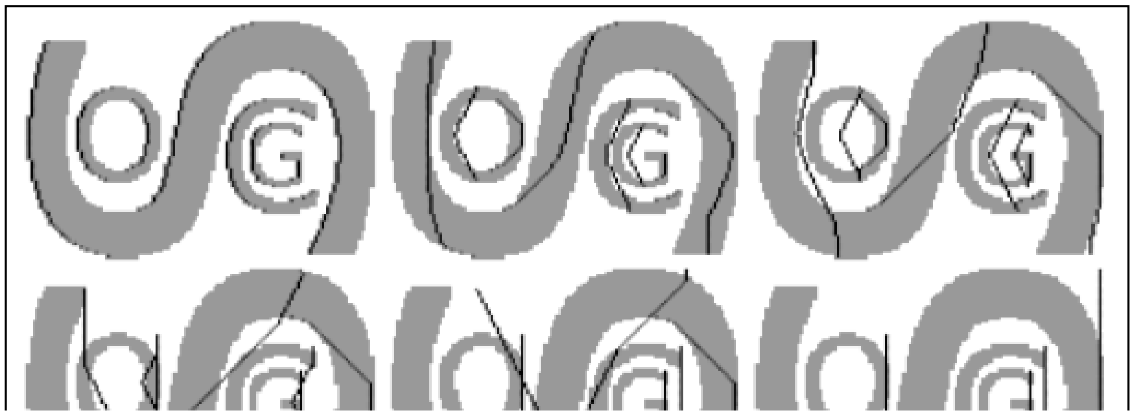
Engineered MP Algorithms

- 4^{th} approach: Situation where opposite flooding fails
  - Convex hulls intersect



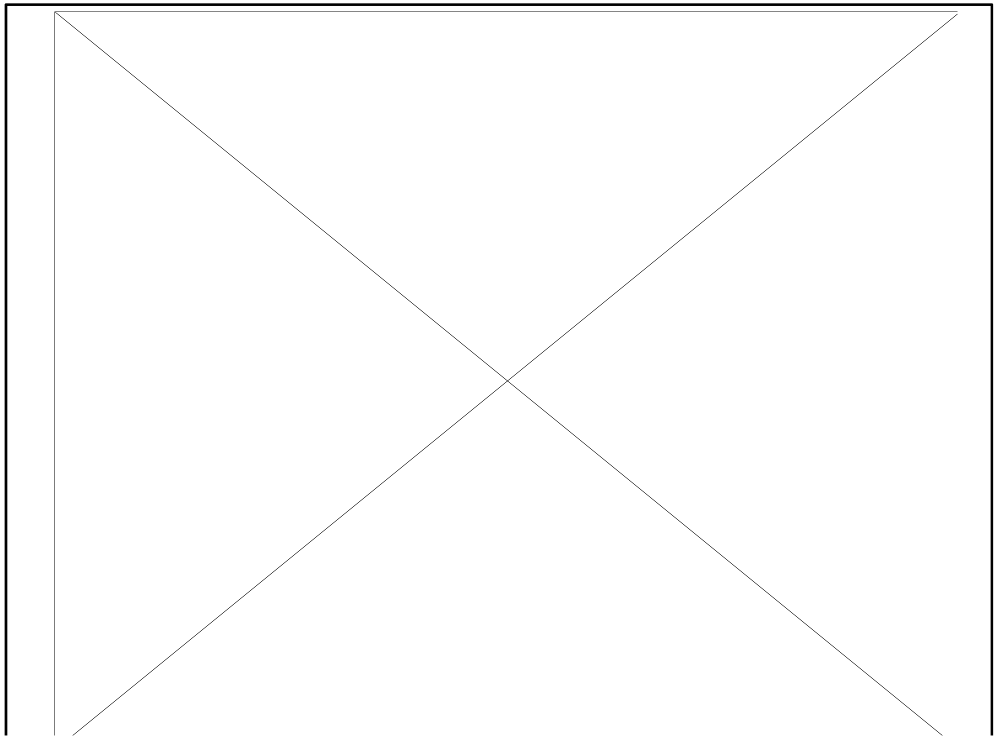
Engineered MP Algorithms

- 5th approach: Pearl Chain
  [in cooperation with S.Fekete, A. Kroeller, C. Schmidt , TUB]
  - MPs belonging to same object are linked to each other
  - No neighboured MPs are more than one pixel away



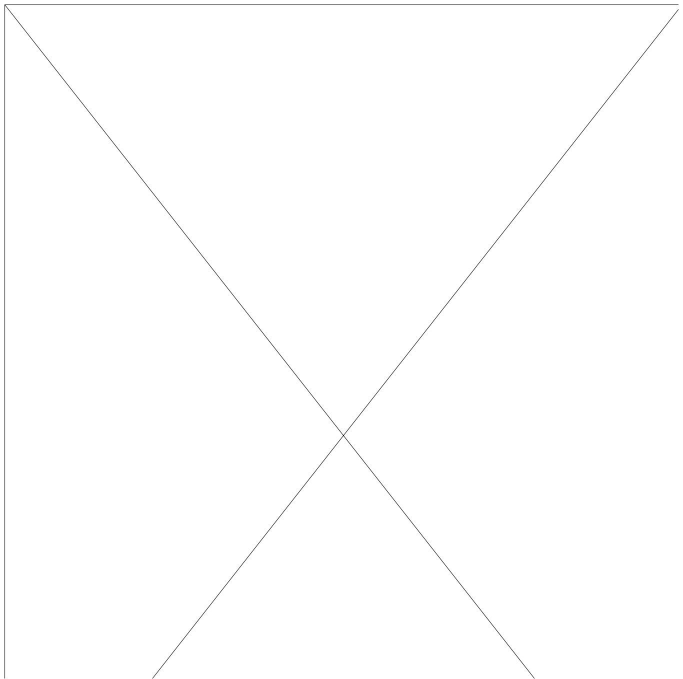
Engineered MP Algorithms

- 5th approach: Pearl Chain
  - Simulation



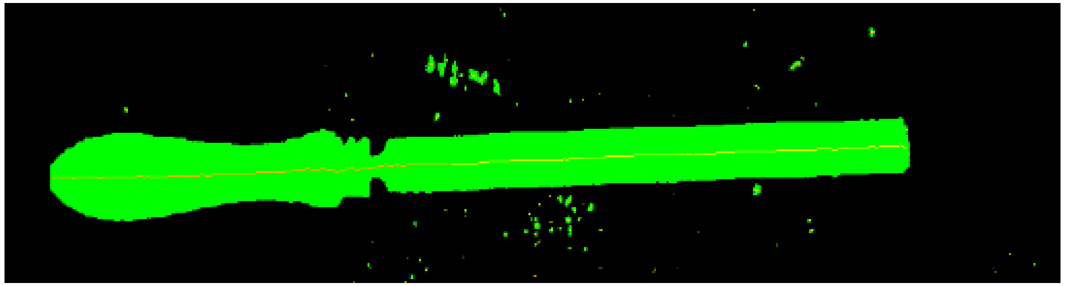
Engineered MP Algorithms

- MPs can more than detection of centroids
  - Path planning
  - 15.000 images with VGA size @ 100 MHz

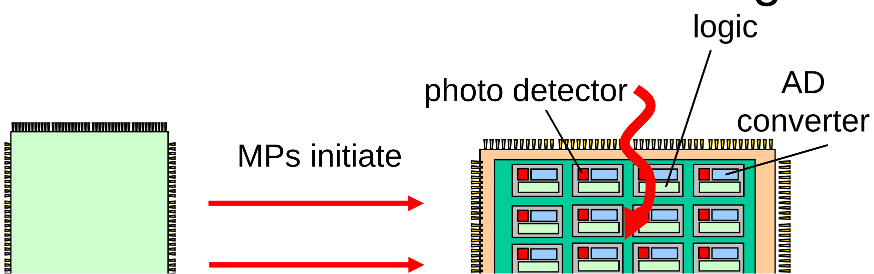


Hardware Realisations for Emergent Algorithms

- Undesired emergence
  - Caused by noise

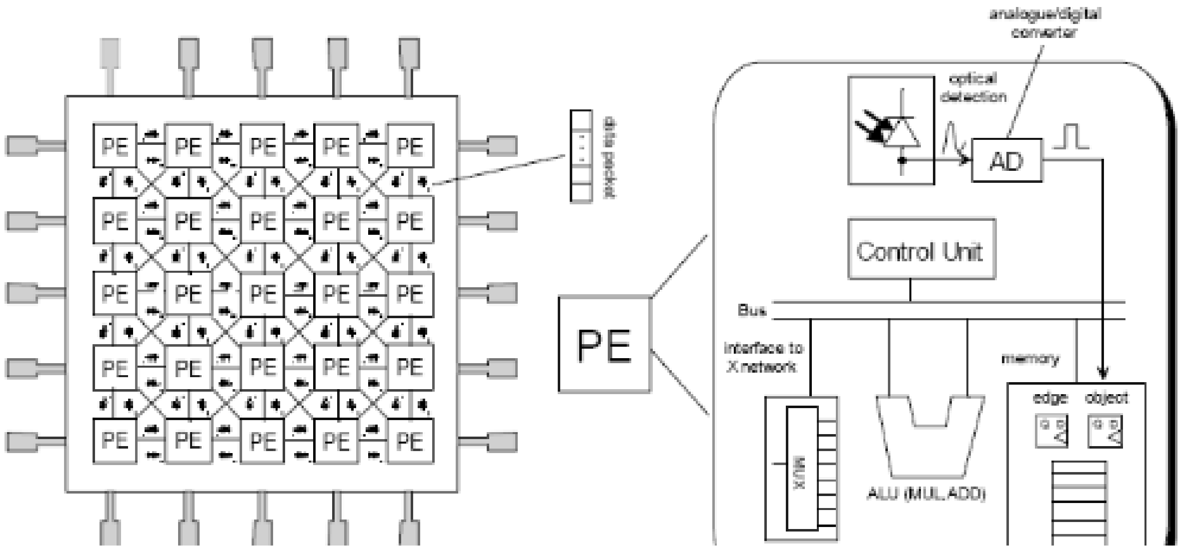


- Heterogeneous architecture – processor field + observer processor
  - Observer processor filters out undesired emergence



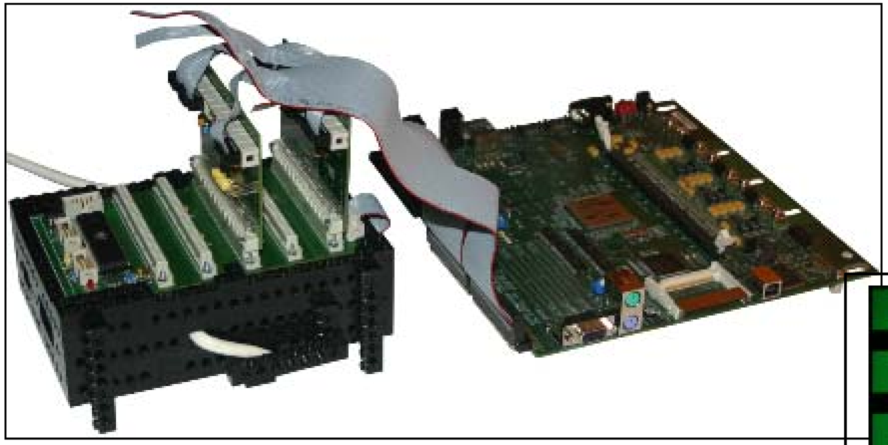
Hardware Realisations for Emergent Algorithms

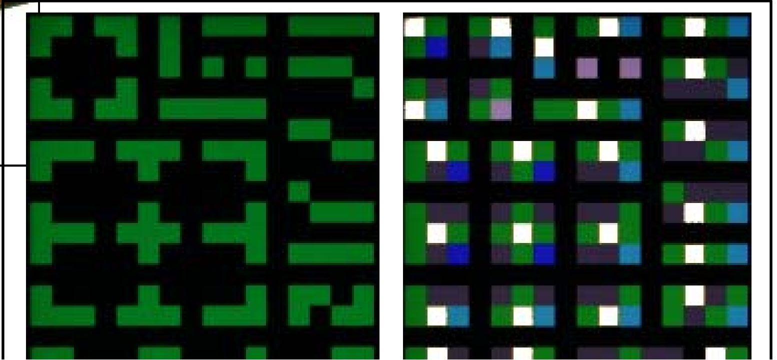
- VHDL
- Parameterized array:
  - Number of PEs
  - Neighbourhood/Connectivity
  - Data width
- Parameterized PEs
  - State machine (propagation)
  - Registers, Operations
- Programmable PEs
  - Microprogram
  - Conditions



Hardware Realisations for Emergent Algorithms

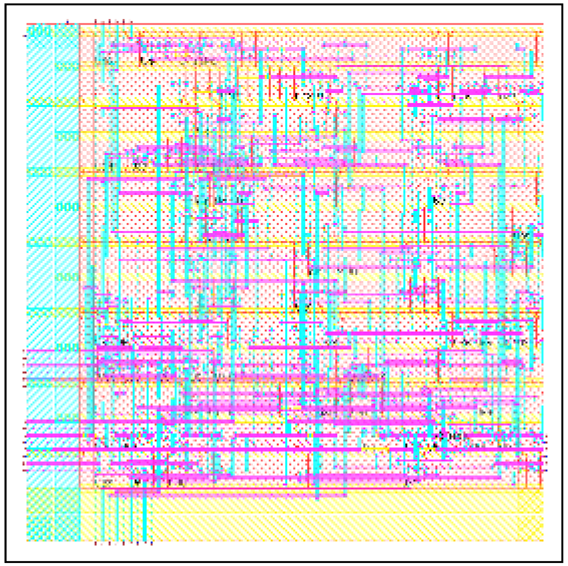
- Application-specific solutions for flooding algorithm
  - Protoyping in FPGA (Virtex-II) evaluation board
  - Worst case: 130.662 frames per second (26 x 14 pixels)
  - For MegaPixel resolution: 1.220 frames





Hardware Realisations for Emergent Algorithms

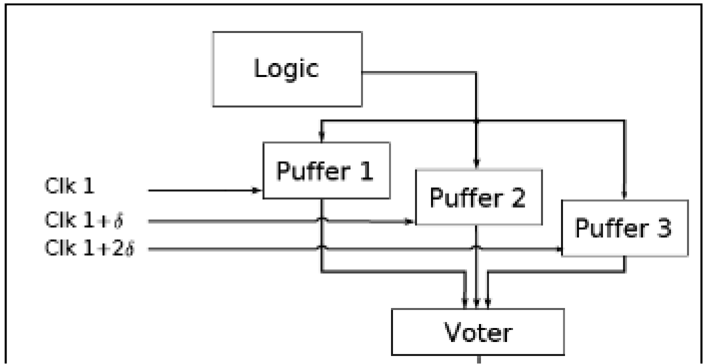
- Actual target platform is an ASIC

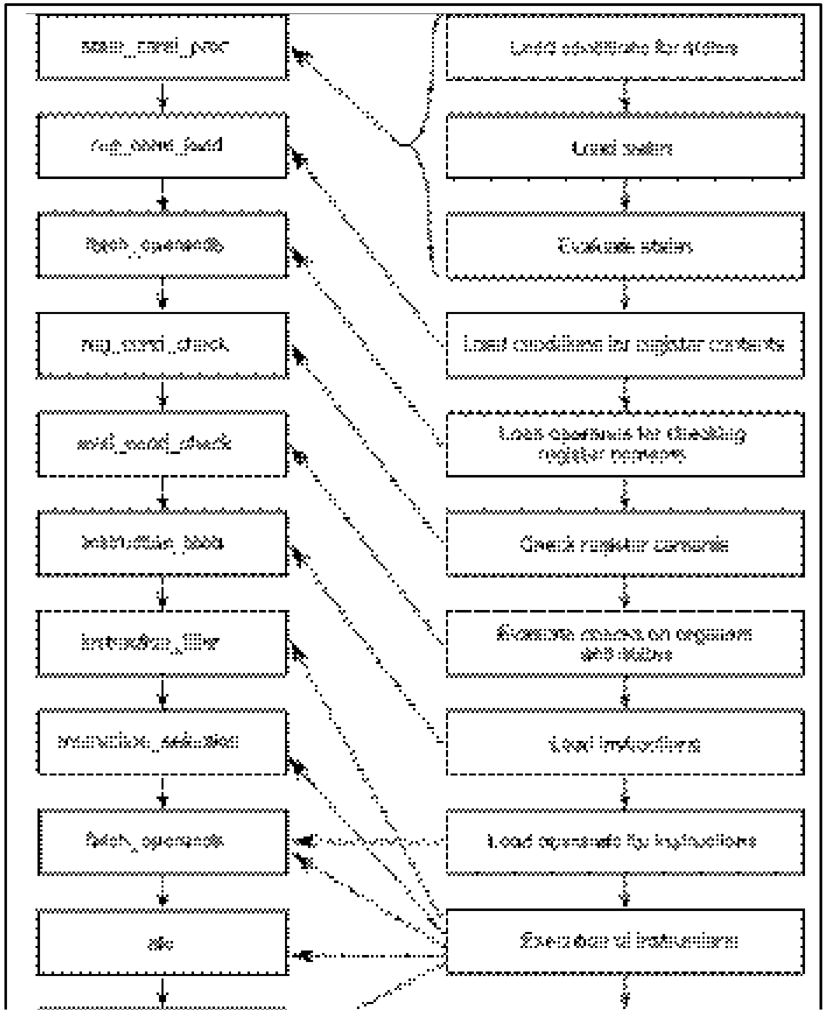


  - 222 × 222 pixels with chip of size 1 cm² (0.90 nm UMC, 6 metal layers)
  - @50 MHz 40.000 images per second

Hardware Realisations for Emergent Algorithms

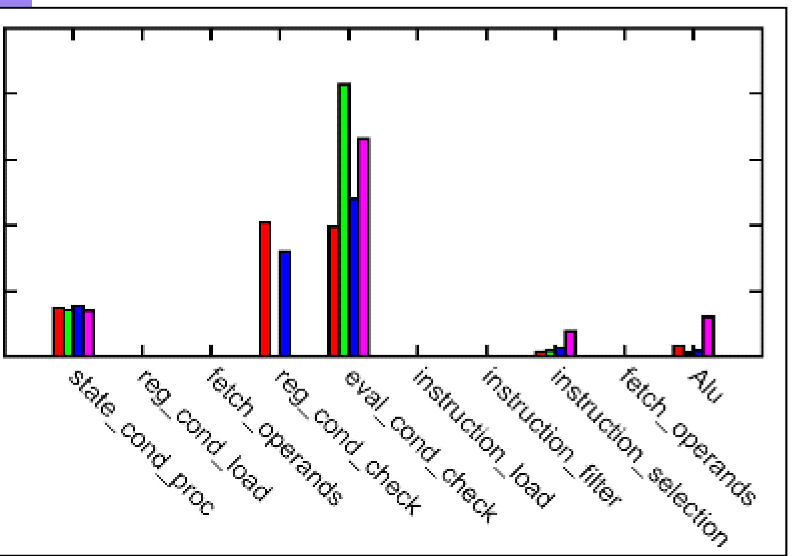
- Programmable microprogam unit
- Processing with pipeline structures
  - Fault-tolerant pipeline structures using locally operation mechanisms (cooperation with ASOC)

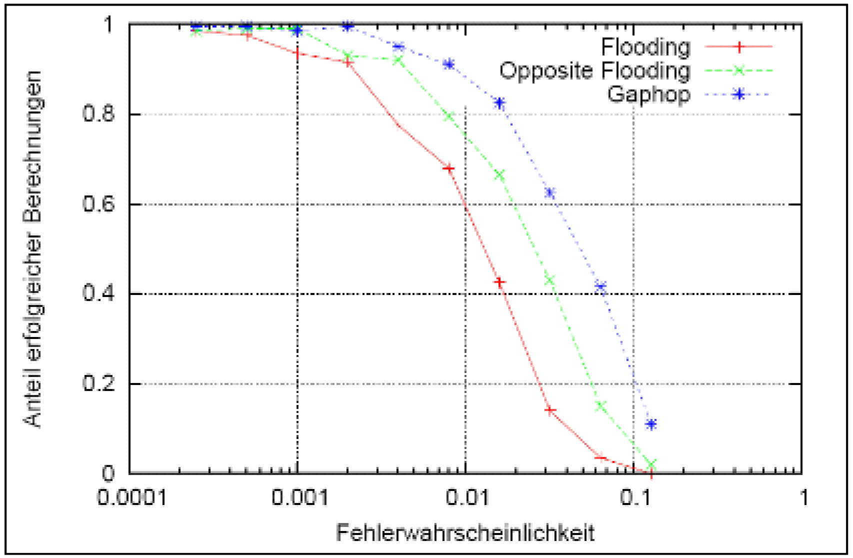




Hardware Realisations for Emergent Algorithms

- Carried out stress tests and weak-point analysis
  - Combination of gaphop, flooding and opposite flooding for different fault injection rates



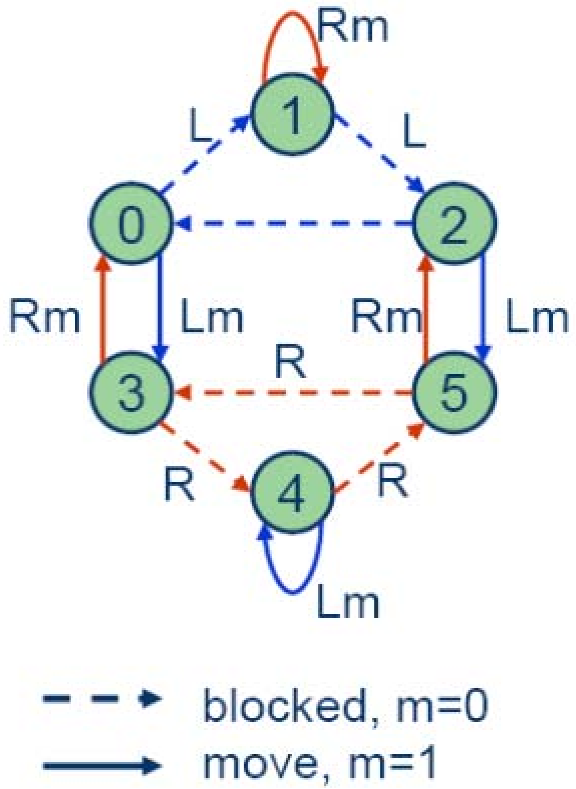


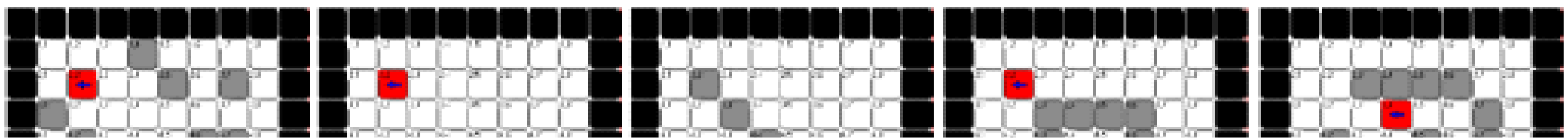
Evolving emergent MP Algorithms

- Manual engineering can be cumbersome
- Evolution is
  - More general
  - Possibly easier
  - Possibly faster

Evolving emergent MP-Algorithms

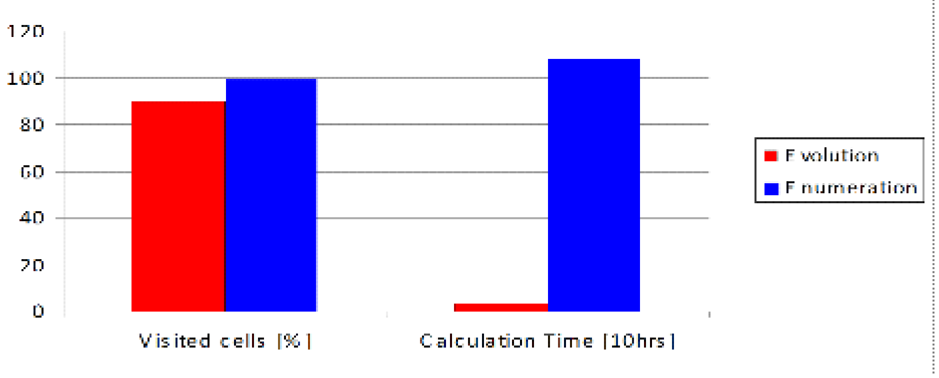
- Creatures' Exploration Problem
  - Question: Best 6-state-automaton?
  - 8.92 x 10^{12} possible automata
    -> simulation of all expensive
  - Simulating more states impossible
  - Evolution helpful?



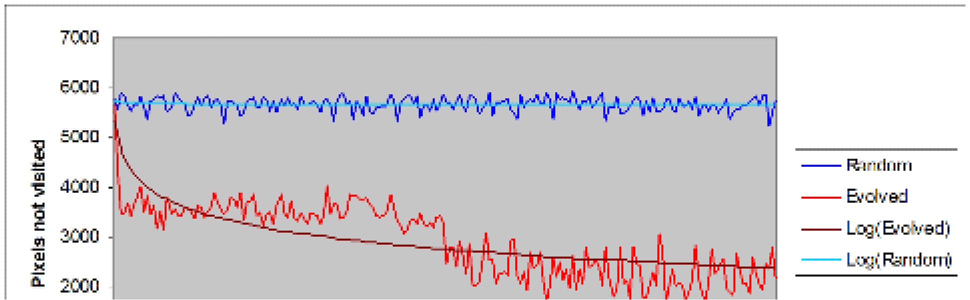


Evolving emergent MP Algorithms

- Comparison: enumeration vs. evolution for one state agent



- Comparison evolution vs. random selection



Evolving emergent MP Algorithms

- Evolution of multi-agents with multi-states
  - Visited cells
    - effectivity

    (max.: 13576)

		States				
		1	3	5	8	Ø
	1	2172	11070	11070	10999	9638,9
	2	5704	12787	12850	13019	11962,1
	3	7183	13436	13462	13456	12666,8
	4	8300	13573	13571	13571	12908,8
Agents	5	8785	13575	13573	13576	12975,1
	6	9500	13575	13575	13576	13066,1
	7	9921	13574	13576	13576	13118,9
	8	10270	13576	13576	13576	13162,8
	Ø	7729,4	13145,8	13156,6	13168,6	12437,4

  - Required steps
    - efficiency

		States				
		1	3	5	8	
	1	310.000	223.861	228.218	227.021	241.869
	2	310.000	140.970	134.313	150.984	187.225
	3	285.527	108.579	103.171	95.291	126.303
	4	262.993	81.904	64.218	62.813	119.786
Agents	5	257.930	61.279	61.998	47.481	99.755

Summary

- Appropriate emergent MP algorithms found
  - Fast enough to fullfill ms requirements
  - Offering flexibility
  - Challenge: the local memory requirement

- Hardware realisation of MP algorithms
  - FPGA prototypes and ASIC simulations proved feasibility
  - Practical resolutions requires ASIC currently
  - Redundancy on algorithm level and on implementation level (locally operating fault-tolerant scheme) offer high robustness

- Evolutionary MP design

Publications

- D. Fey, C. Gaede, A. Loos, and M. Komann
  A New Marching Pixels Algorithm for Application-Specific Vision Chips for Fast Detection of Objects' Centroids
  Proceedings Parallel and Distributed Computing and Systems (PDCS) 2008, Orlando, Florida, USA, November 2008.

- M. Schmidt, D. Fey
  A Parallel Path Planning Approach based on Organic Computing Principles
  Proceedings Parallel and Distributed Computing and Systems (PDCS) 2008, Orlando, Florida, USA, November 2008.

- M. Komann, A. Mainka, and D. Fey
  Comparison of evolving uniform, non-uniform cellular automaton, and genetic programming for centroid detection with hardware agents.
  In V. E. Malyshkin, editor, PaCT, volume 4671, LNCS 4671, pp. 432–441. Springer, 2007.

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  in Adamatzky, A.; Alonso-Sanz, R.; Lawniczak, A.; Martinez, G. J.; Morita, K. & Worsch, T. (ed.): AUTOMATA-2008 Theory and Applications of Cellular Automata, 228-241, 2008.

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  submitted to Automata EuroGP 2009, 12th European Conference on Genetic Programming, EvoStar 2009,

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  Proceedings ACM International Conference on Computing Frontiers 2005, pp. 1-9, Ischia, Italy, May 2005.

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  Proceedings of the 2008 conference on Computing frontiers (CF’08), ACM, pp. 221-230, 2008.