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Differentially Evolving Memory Ensembles

Pareto Optimization based on Computational Intelligence for Embedded Memories on a System Level

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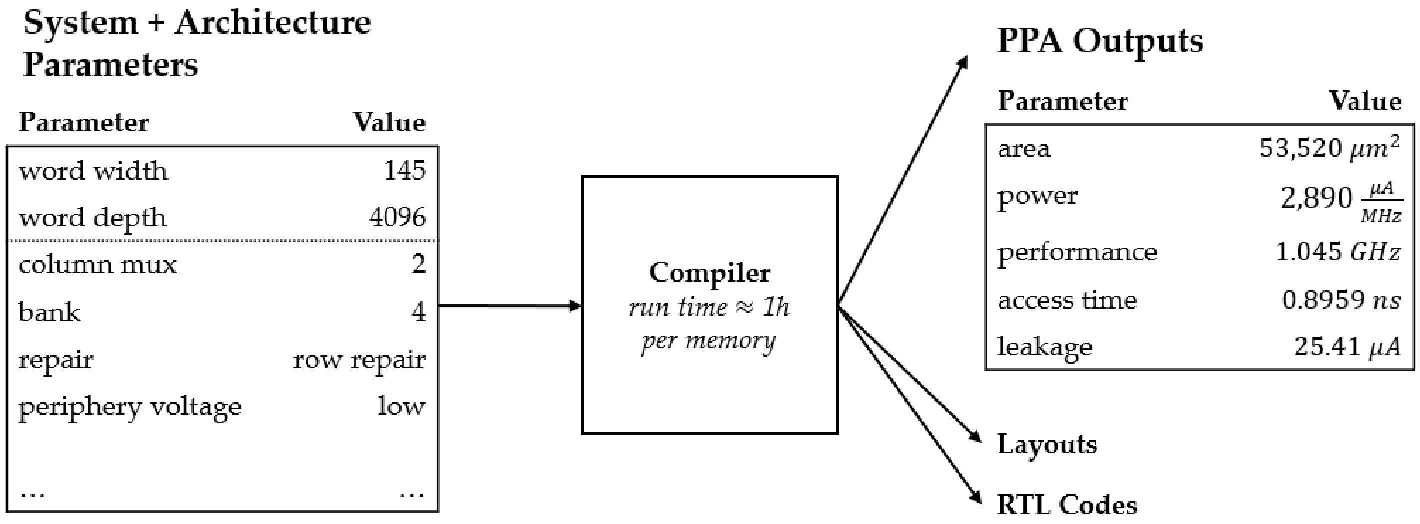
Agenda

Motivation (1/2)

- Memory compilers generate embedded memories
- Architectural parameters require “knob-tuning”



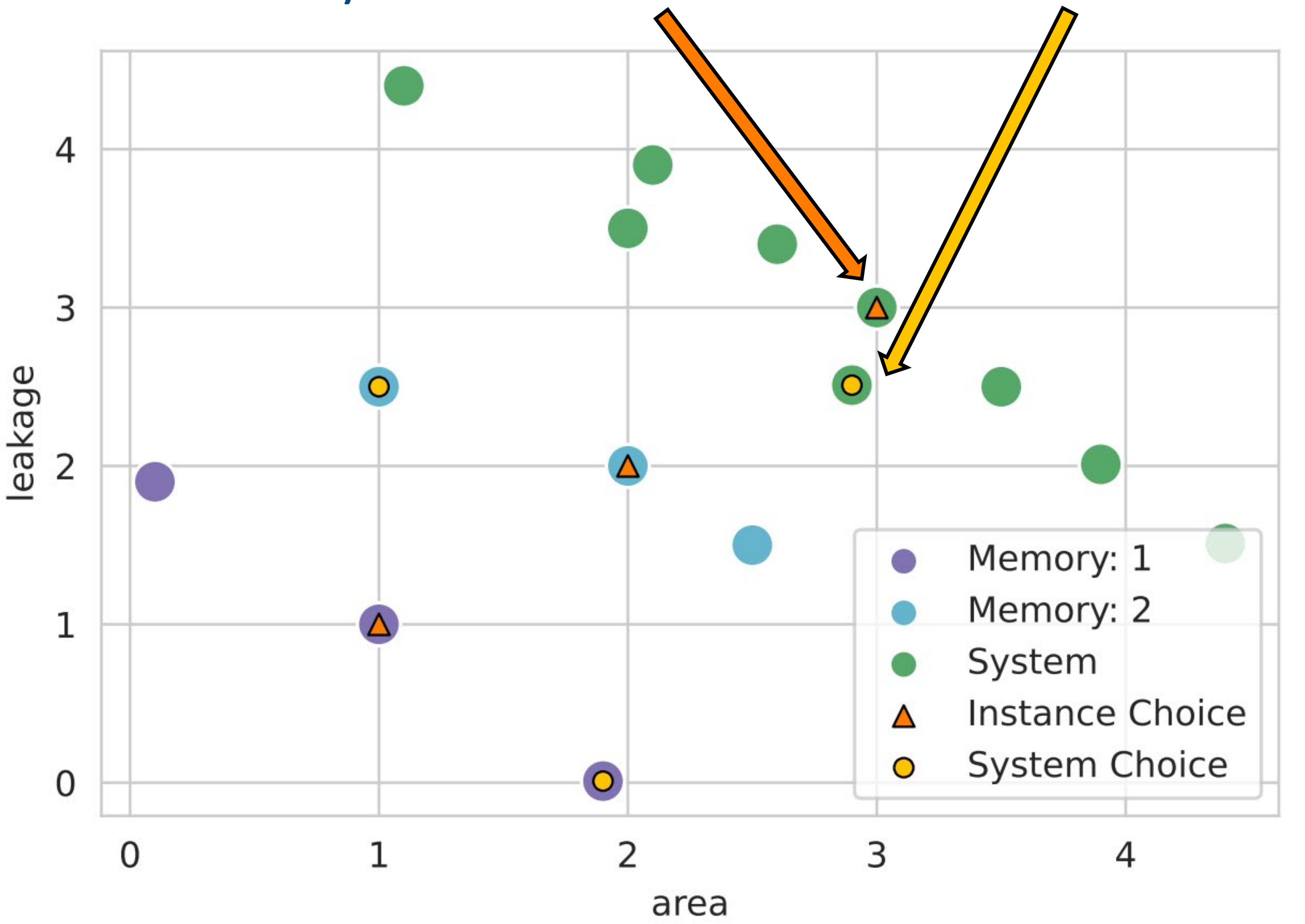
- Conflicting objectives:
  power, performance, and area (PPA)
- Modern ICs contain 500-10,000 memories → substantial PPA impact

- Feasibility constraints

Motivation (2/2)

- Consider the combinatorial Pareto front on system level
- System-level optimization may yield better choice than sequential instance optimization

The result of choosing the balanced trade-off per memory instance… is objectively dominated on the system level.



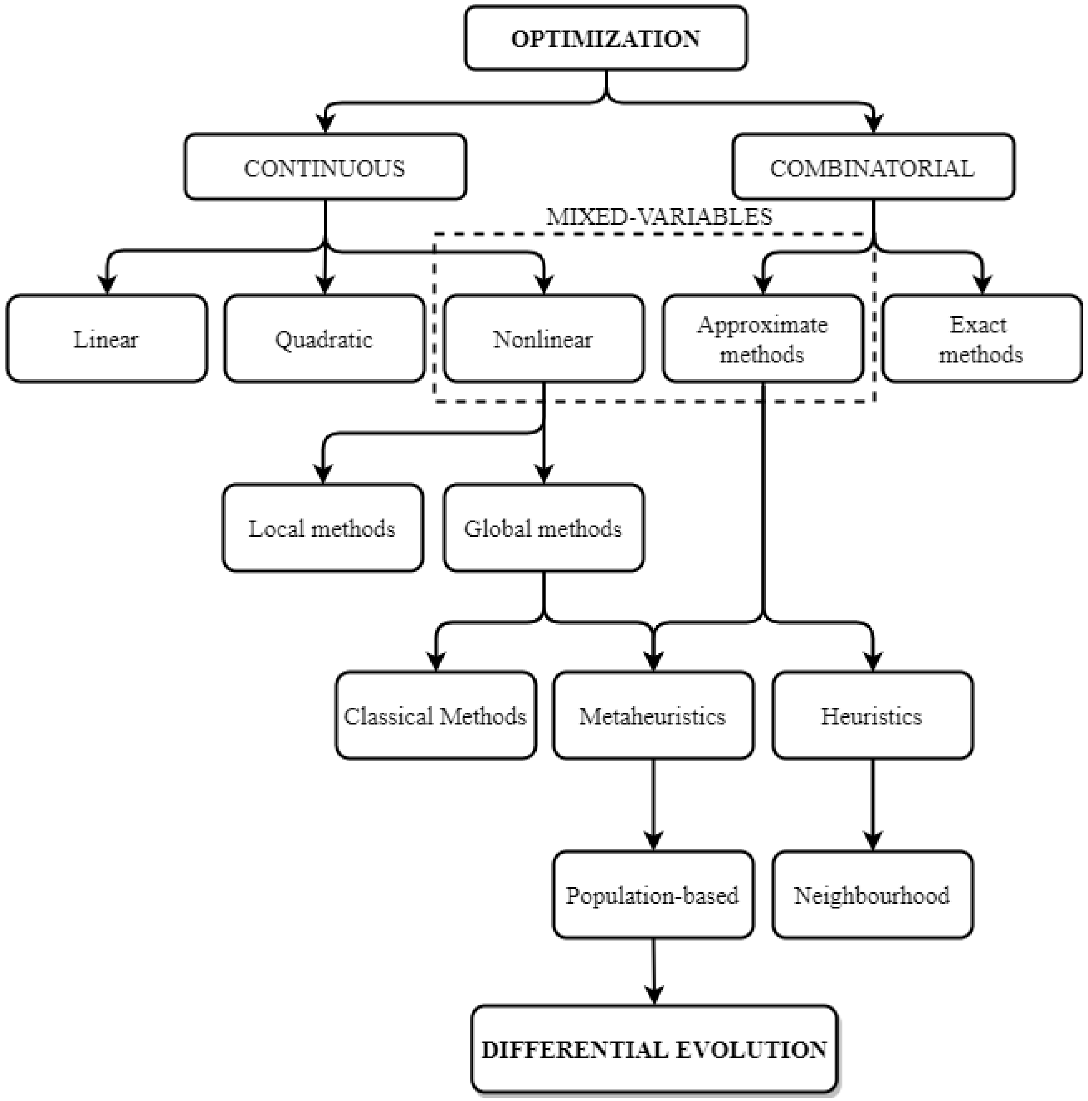
Proposed Method (1/4)

- Algorithm selection from 40 choices through requirement-traceability matrix
- Match problem characteristics to algorithm characteristics

Optimization algorithm selection requirement traceability matrix																
Chacteristics required for the problem / Optimization Algorithms	multi objective optimization	discrete variable values	continuous objective function	high dimensional solution vector	convergence to global optimum	computationally inexpensive	non-convex problem	fast convergence	non-linear functions	robustness	stability	stochastic methods	scalibility	good exploration of the design space	executable in parallel	Score
Importance	3	1	2	3	1	0	1	3	1	2	1	2	3	2	3	-
Differential evolution (DE)	1	1	1	1	1		1	1	1	1		1	1		1	25
Artificial bee colony (ABC)	1	1	1		1		1	1	1	1		1		1		18
Ant colony optimization	1	1		1	1		1	1	1					1		15
Bat algorithm (BA)	1	1	1		1		1		1	1	1			1		14
Artificial fish swarm (AFS)	1	1	1		1		1		1	1				1		13
Particle swarm optimization (PSO)	1	1	1	1											1	12
Cuckoo search (CS)	1	1	1					1	1							10
Genetic algorithm (GA)	1	1			1		1		1			1				9

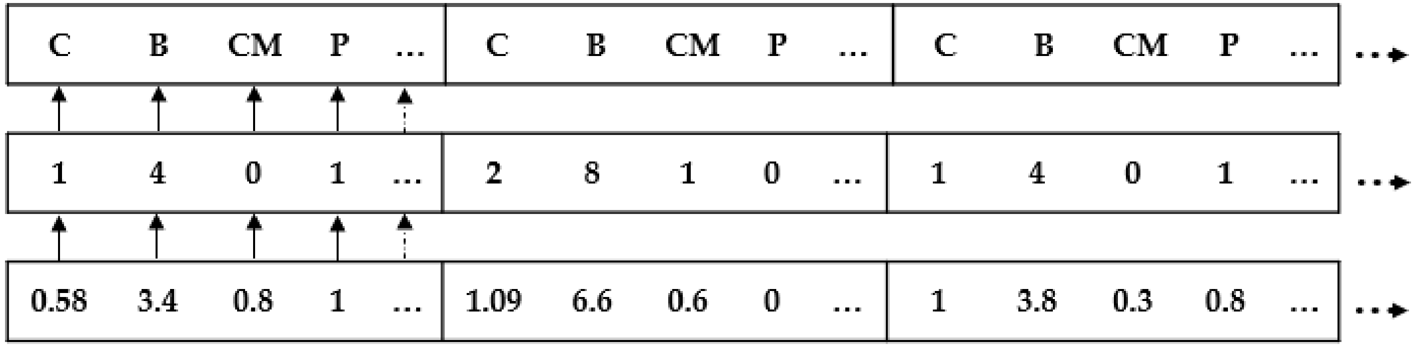
Proposed Method (2/4)

- Differential Evolution
  - evolutionary algorithm
  - metaheuristic
  - population-based
  - global
  - few control parameters



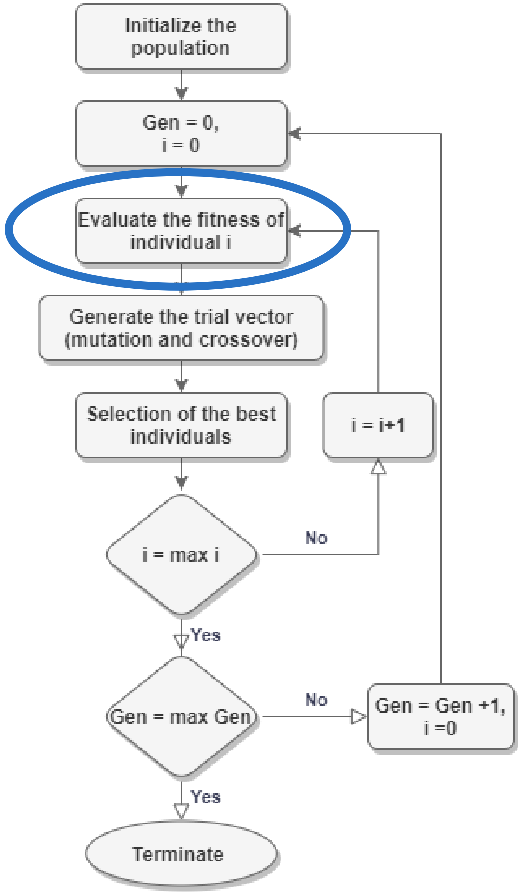
Proposed Method (3/4)

Repairing individuals to feasible compiler parameters:



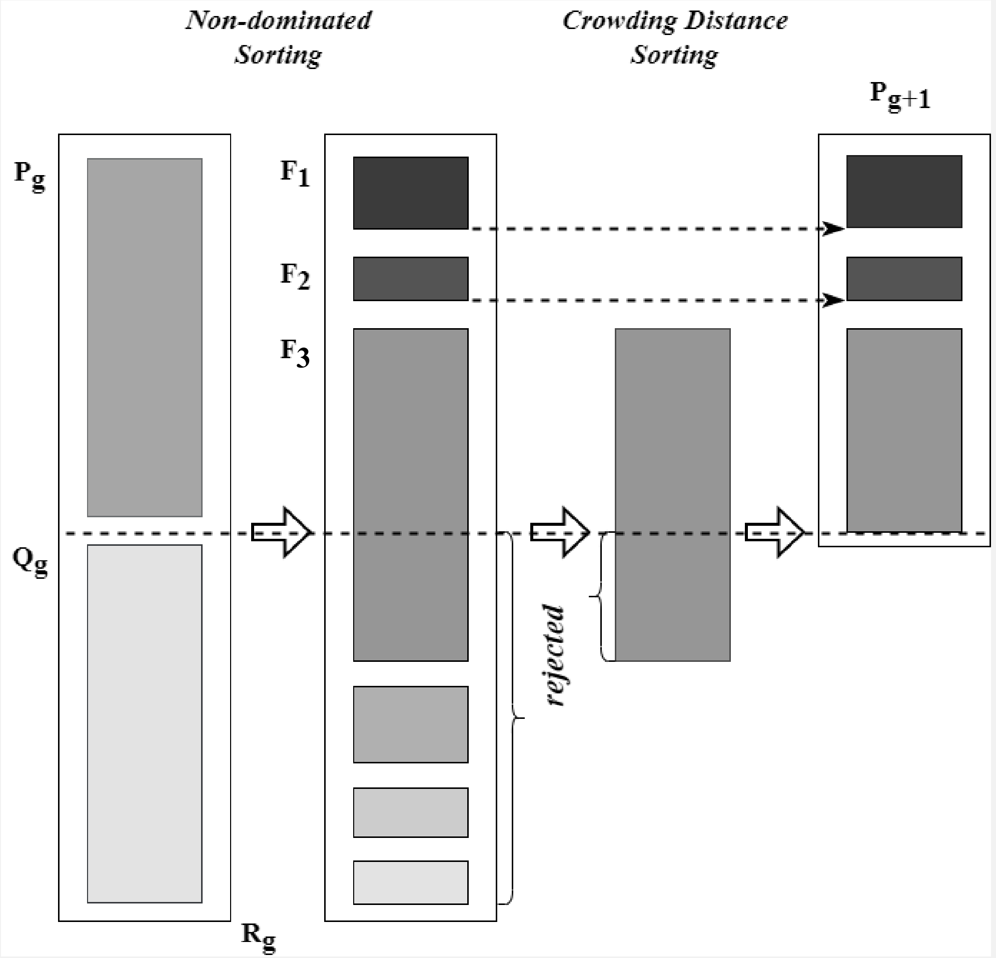
A look-up table for the transformation of the parameters:

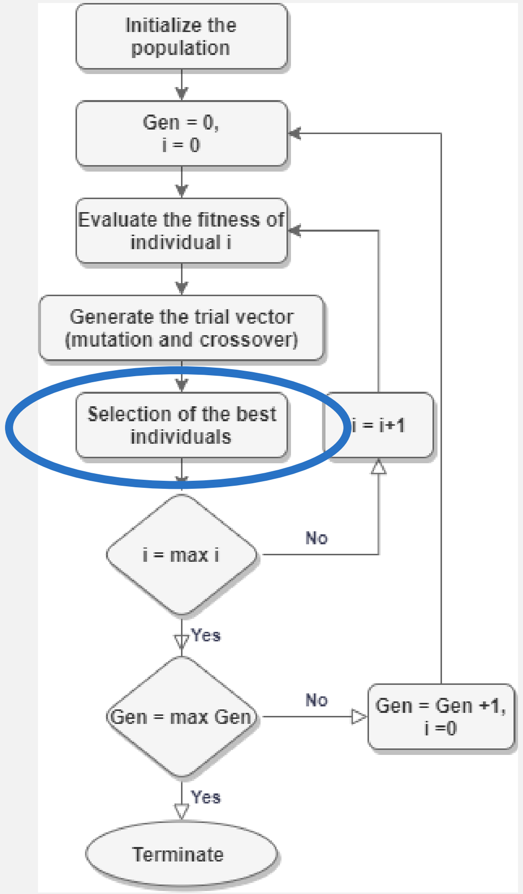
Compiler	V_{th}	$\overline{V_{th}}$
compiler A	low-vt	0
compiler A	standard-vt	1
compiler A	high-vt	2
compiler B	low-vt	0
…	…	…



Proposed Method (4/4)

- Selection based on Pareto dominance through NSGA-II
- Non-dominated sorting & crowding distance sorting





Results (1/4)

- Experimental Setup
  - Two systems (A, B)
  - System size: 4 memories
  - Design space per memory: 50-900 candidates
  - System design space: >500M combinations
- Small systems allow exhaustive combinatorial search
  - “Golden baseline”
  - Infeasible for larger systems

Results (2/4)

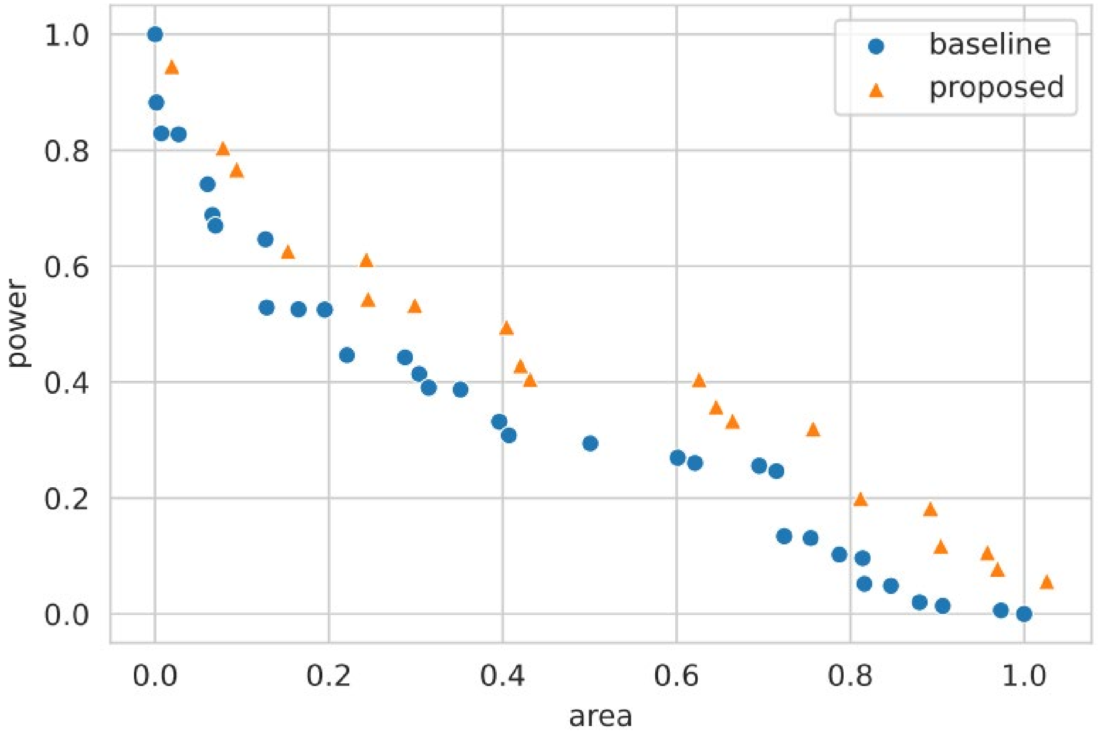
Two main control parameters of differential evolution:
Differentiation constant F; crossover constant CR

Test Case No.	F	CR	NP	No. of Generations	Area $[\mu m^2]$ min	Area $[\mu m^2]$ max	Area $[\mu m^2]$ mean	Power $[\mu A/MHz]$ min	Power $[\mu A/MHz]$ max	Power $[\mu A/MHz]$ mean
1	0.4	0.5	10	20	169.390	172.477	170.770	4.289	4.433	4.369
2	0.8				164.405	174.305	168.910	4.231	4.409	4.322
3	1.2				**163.431**	**172.311**	**167.992**	**4.216**	**4.349**	**4.285**
4	0.4	0.7			166.194	173.493	170.945	4.246	4.386	4.292
5	0.8				167.508	178.270	172.003	4.285	4.506	4.394
6	1.2				168.439	180.569	172.514	4.298	4.471	4.368
7	0.4	0.9			170.925	176.770	174.107	4.303	4.432	4.357
8	0.8				167.378	176.409	172.200	4.284	4.461	4.374
9	1.2				168.554	177.227	173.326	4.333	4.512	4.402

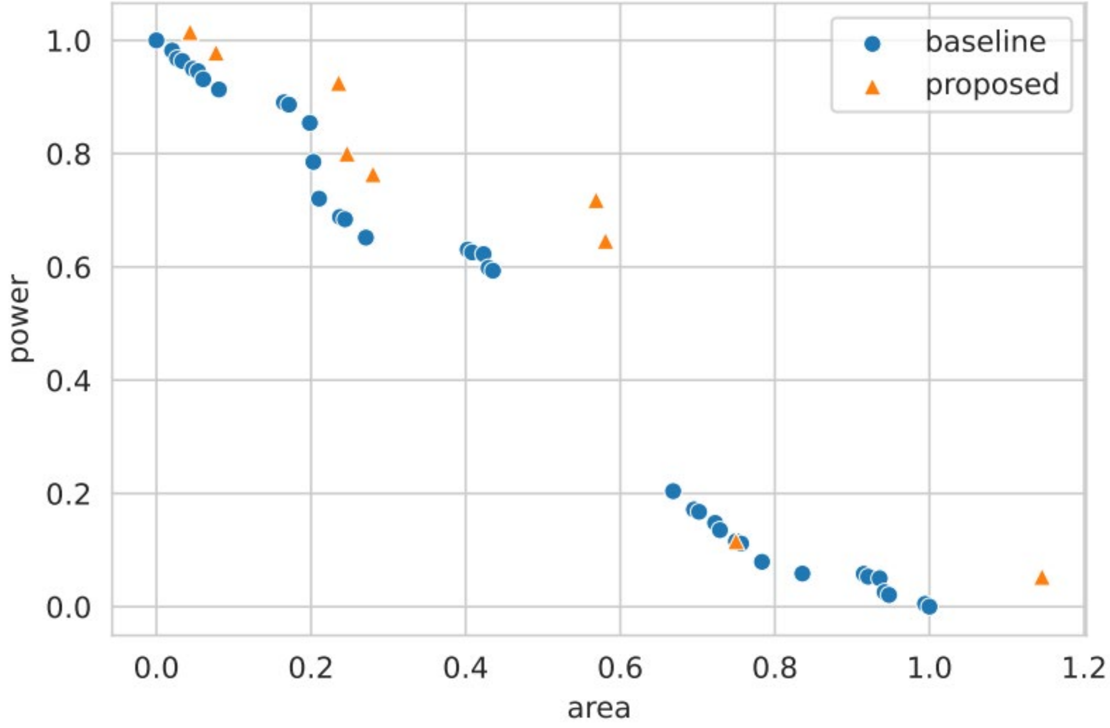
Results (3/4)

Pareto fronts found by proposed method and “golden baseline” for two systems of memories

- System A



- System B



Results (4/4)

Performance indicators for System A

	Exhaustive Search	Proposed Method
# solutions evaluated	644,972,544	2,000
RAM Usage	>100GB	<<1GB
Runtime	20min	9min
Feasibility	Small systems only	Scalable to large systems
Distance from best area	0%	0.54%
Distance from best power	0%	0.75%

Conclusion & Outlook

- Proposed method: Differential Evolution + NSGA-II selection
- Enablement of system optimization – previously infeasible
- < 0.55% distance from best area, <0.75% from best power

- Incorporation of hard constraints on the objective function values
- Dynamic adjustment of control parameters
- Perform experiments on large-scale problems
- Study effect of repair on diversity