Accelerating the Evolution of Evolvable Hardware-based Packet Classifiers

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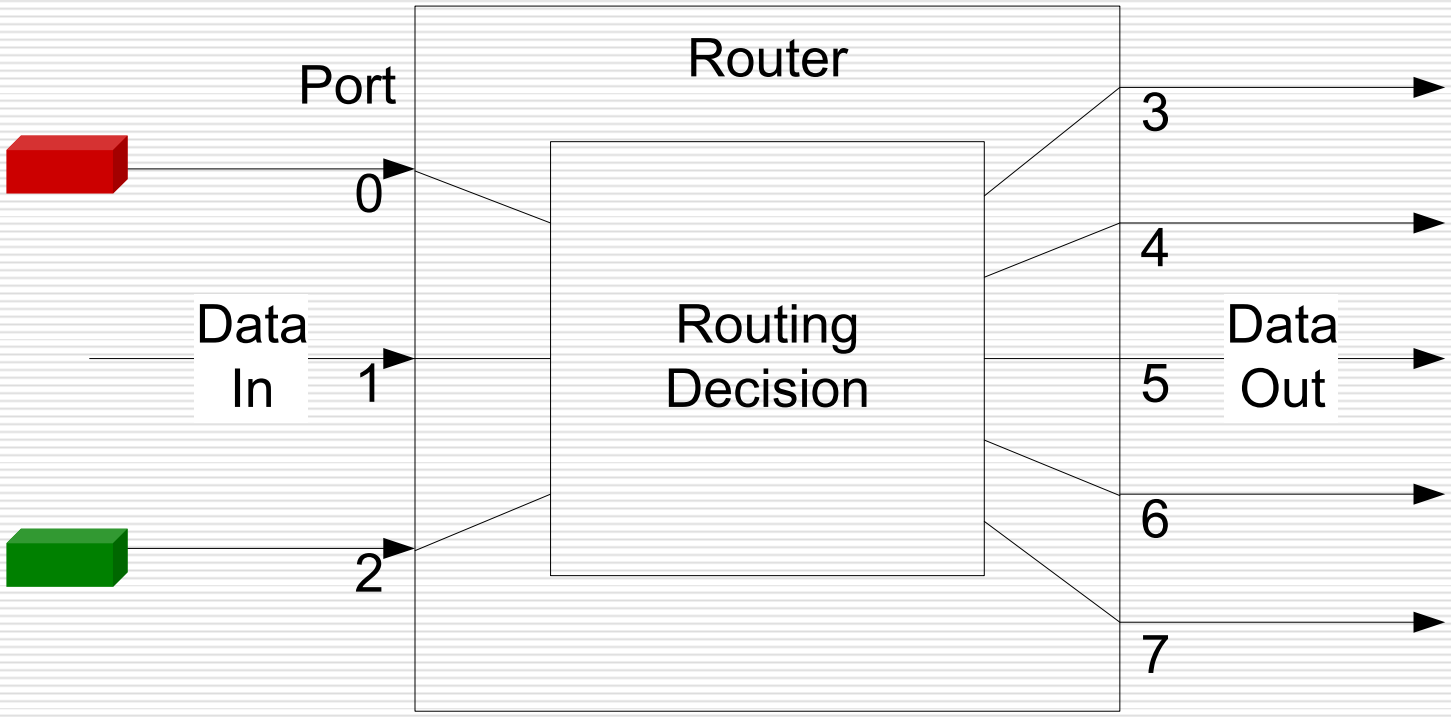
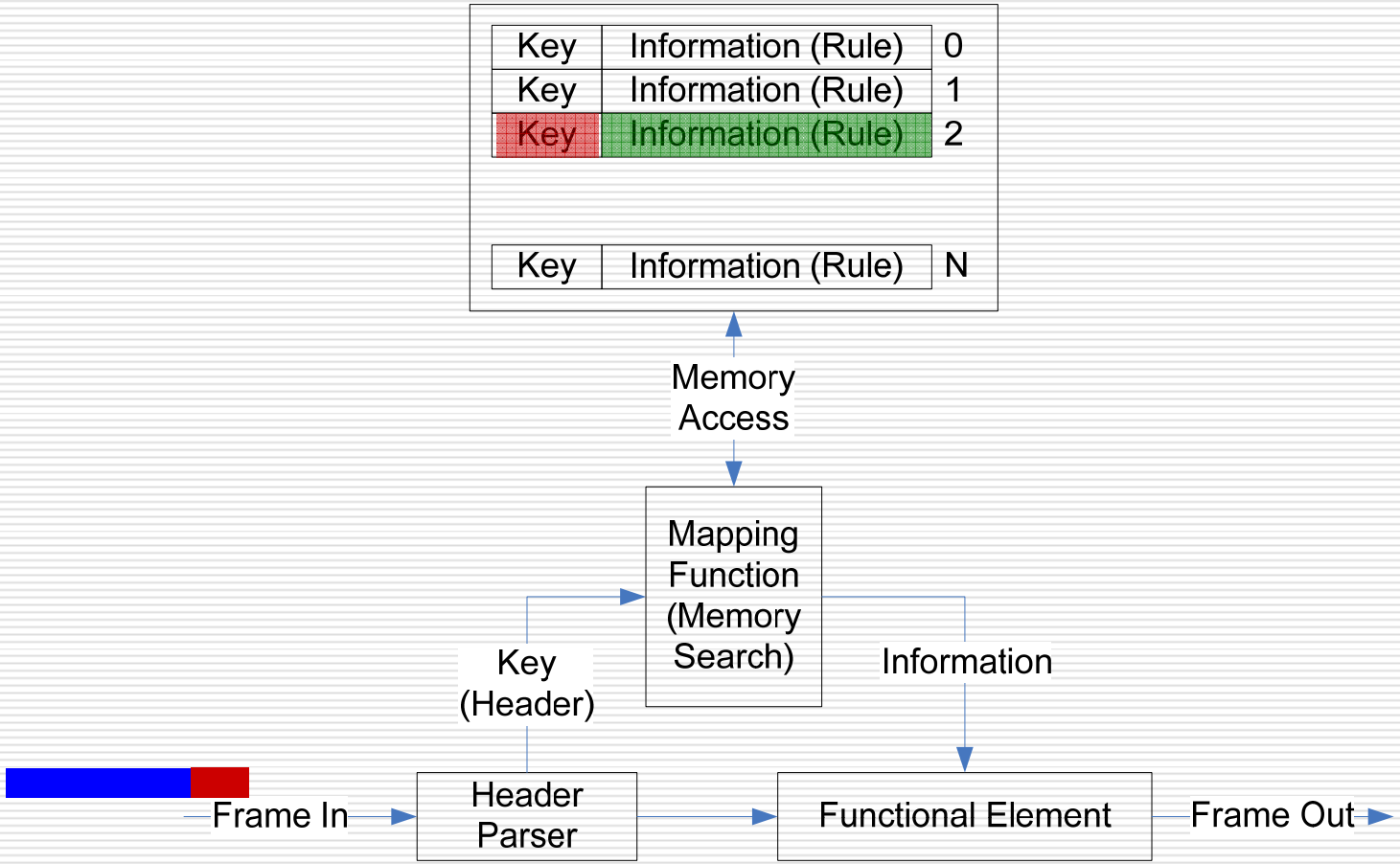
Outline

- Packet-Classification Problem
- Adaptive Hashing in Hardware
- Classifier System
- Fitness Evaluation Acceleration
  - Early Termination
  - Parallel Fitness Evaluation
  - Memory Interleaving
- Conclusion

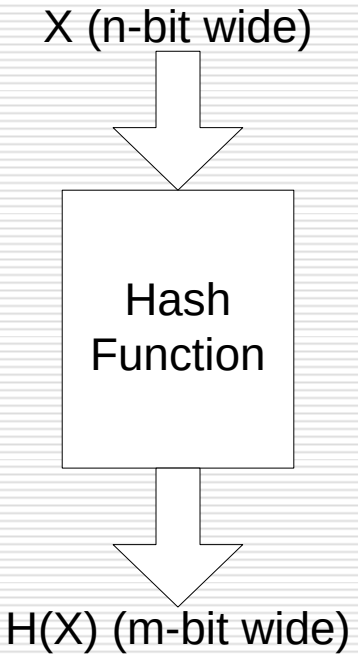
Classification Problem



Classification Problem

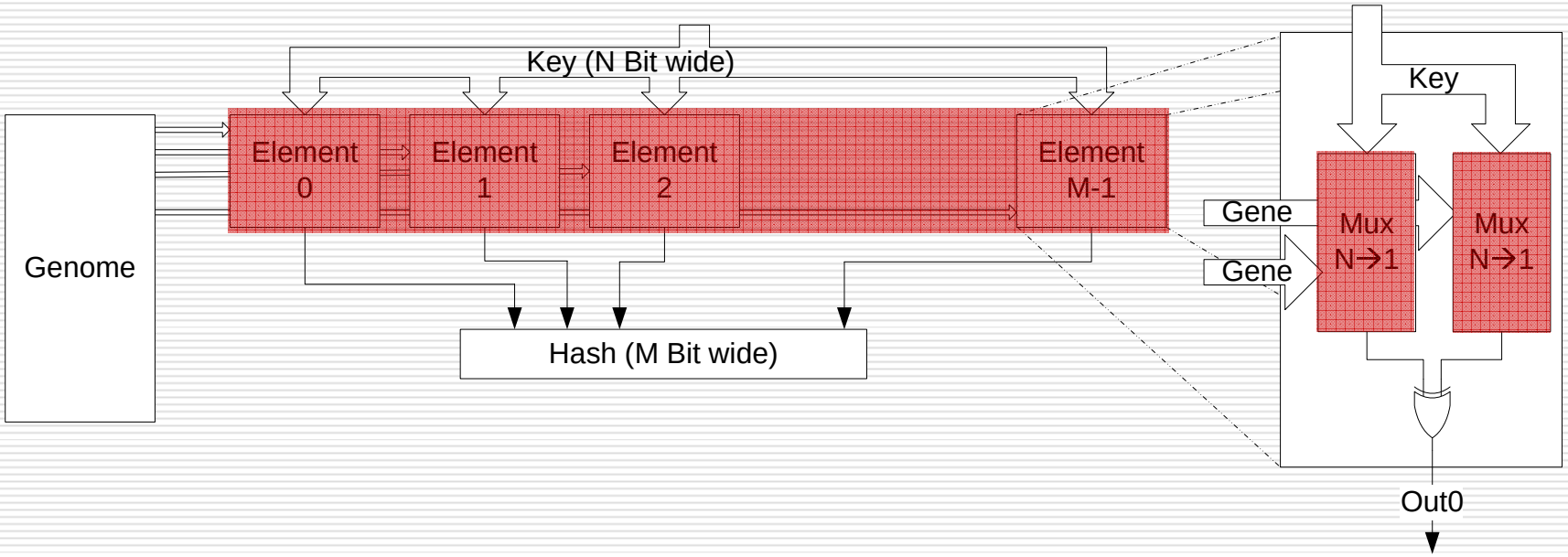


Adaptive Hashing in Hardware



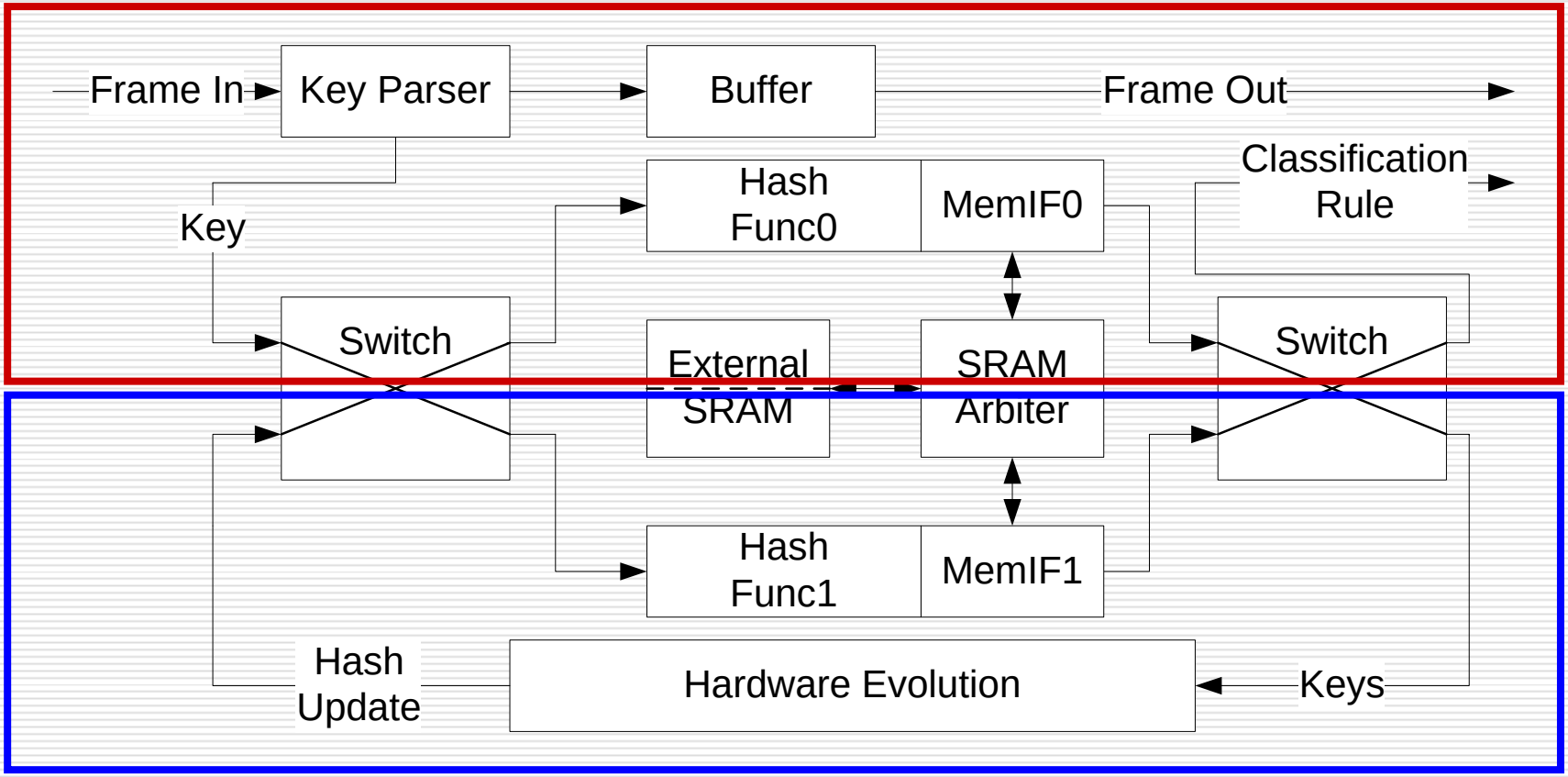
- Collision: $X \neq Y$; $H(X) = H(Y)$
- Resolution
  - Rehashing H(H(X));
  - Linear H(X)+Prime
- Time Complexity: O(1)
- Memory Space : O(N)

Adaptive Hashing in Hardware

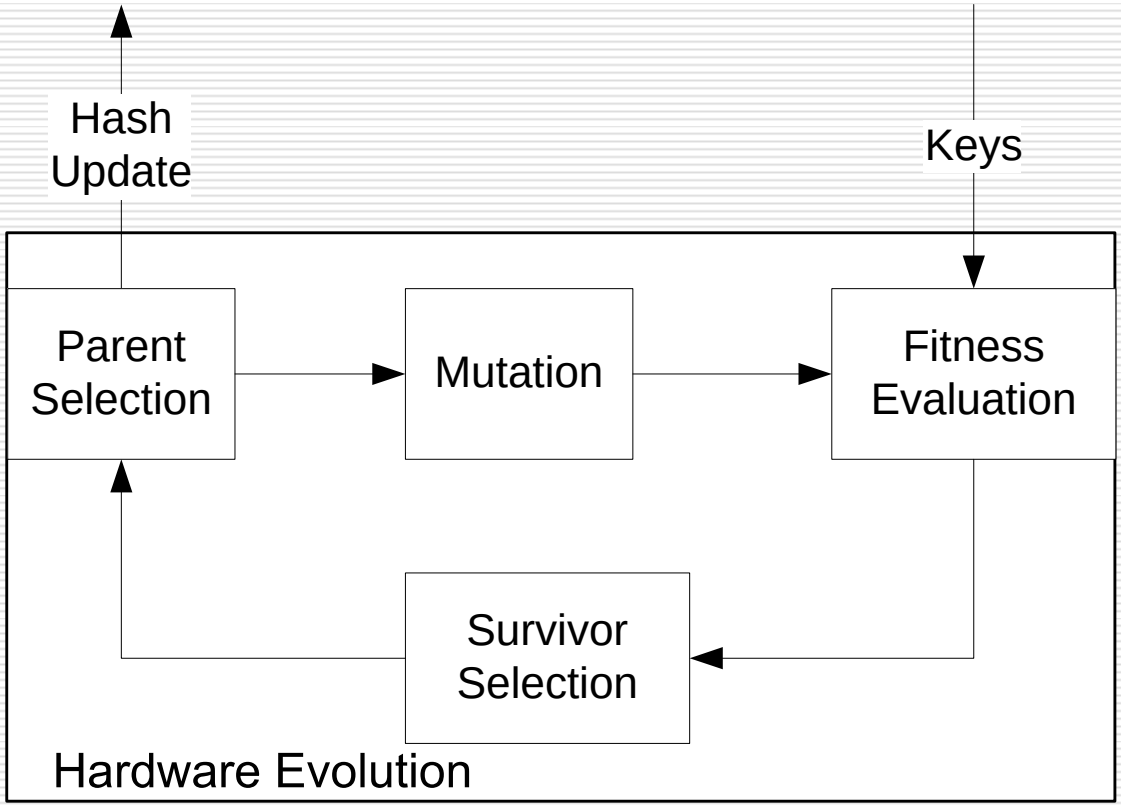


- Genome: $M \cdot 2 \cdot \log_2(N)$

Classifier System



Genetic Algorithm – Implementation in Hardware

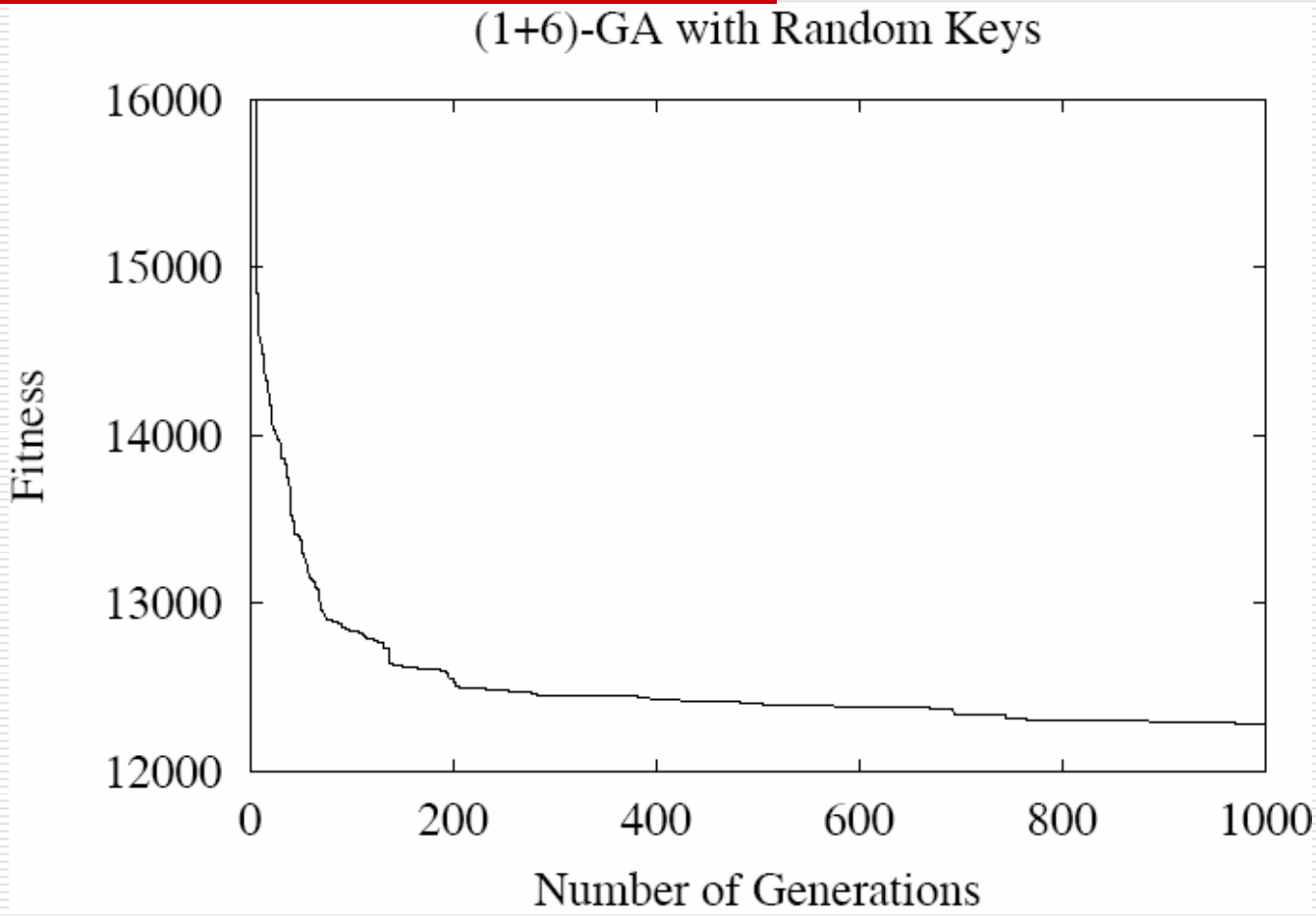


- μ Individuals
- λ Offspring
- Mutation Rate: 1/N
- Survivor Selection: μ new parents out of λ offspring and fittest old parent; (λ,μ)-elitist

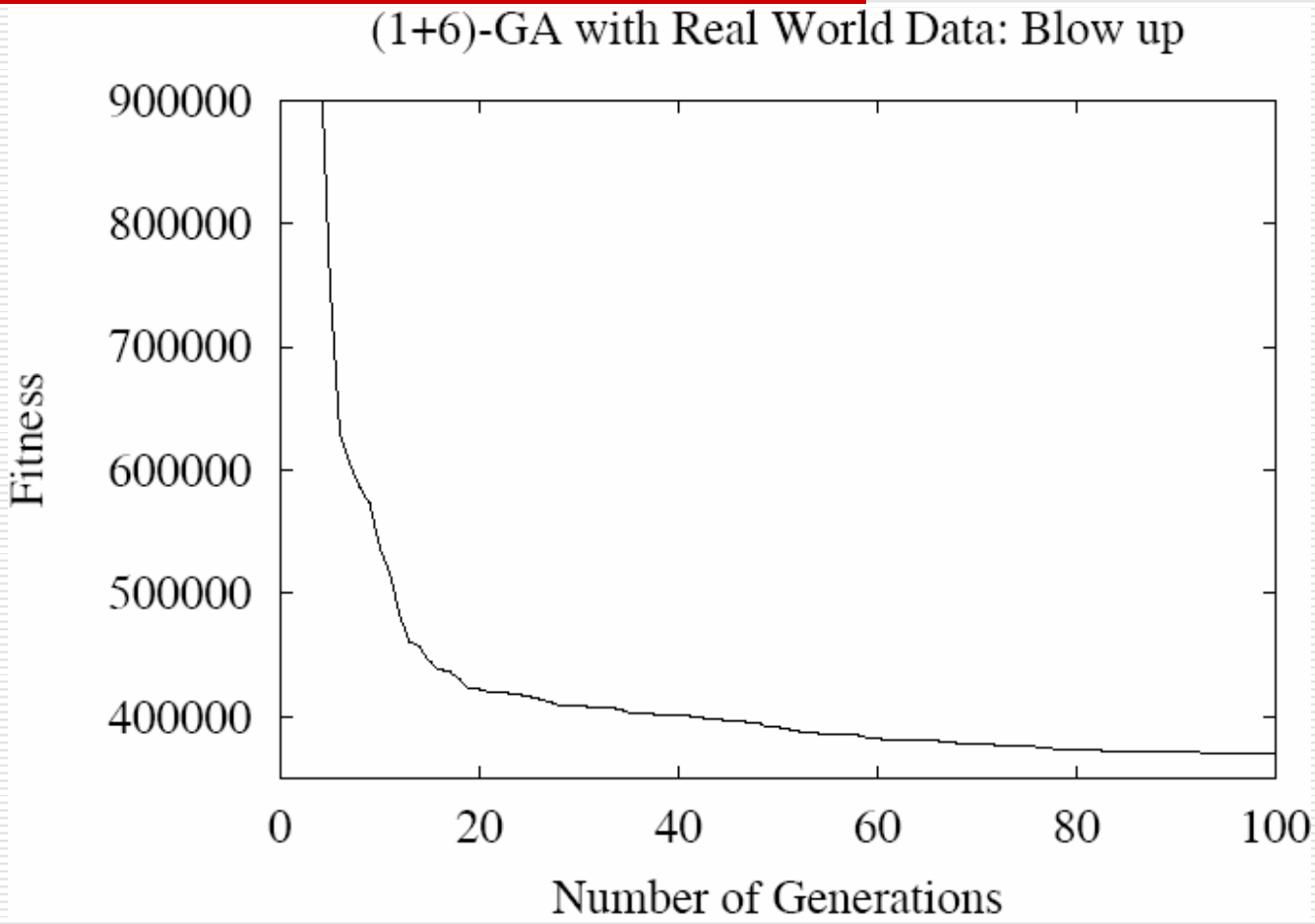
Fitness Evaluation

- Fitness Value ↔ Number of Collisions
  - Fittness Reversed → 0 = perfekt
  - Hash all existing keys
  - H(Key) used in the memory?
    - H(Key) = H(Key)+ prime
    - F++

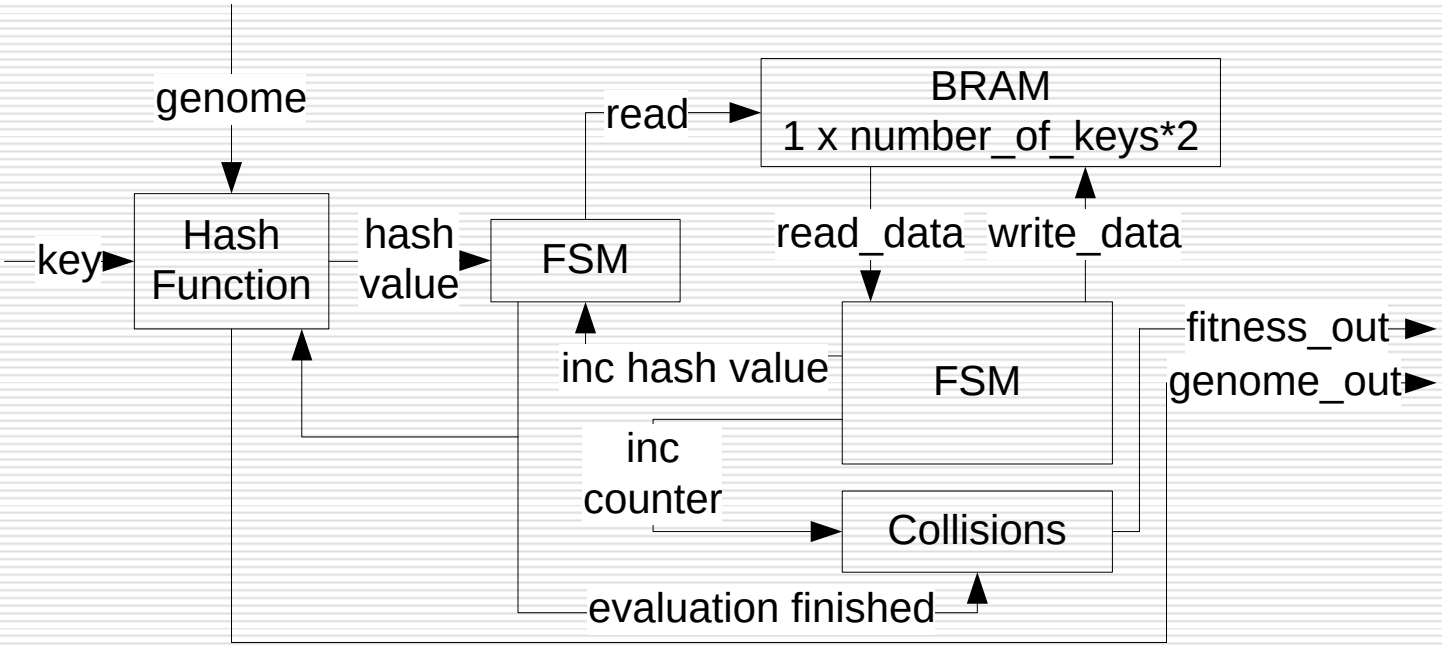
Performance – Random Data



Performance – Real World Data

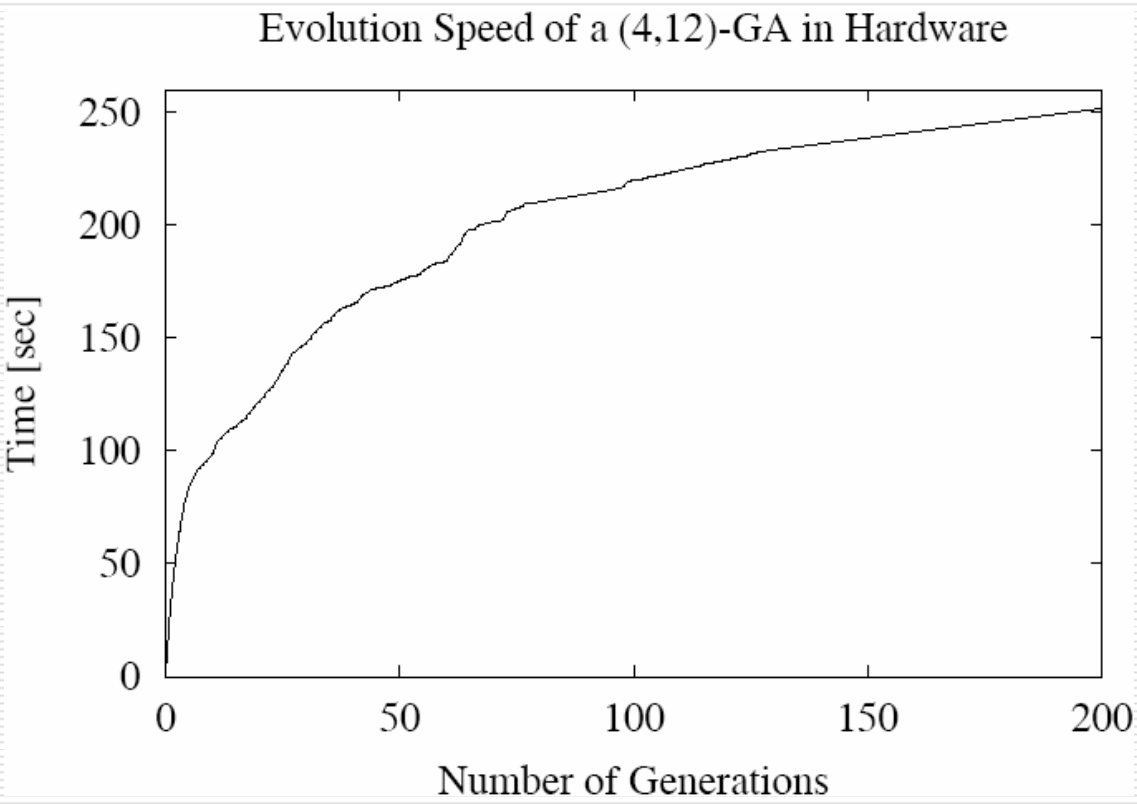


Fitness Evaluation



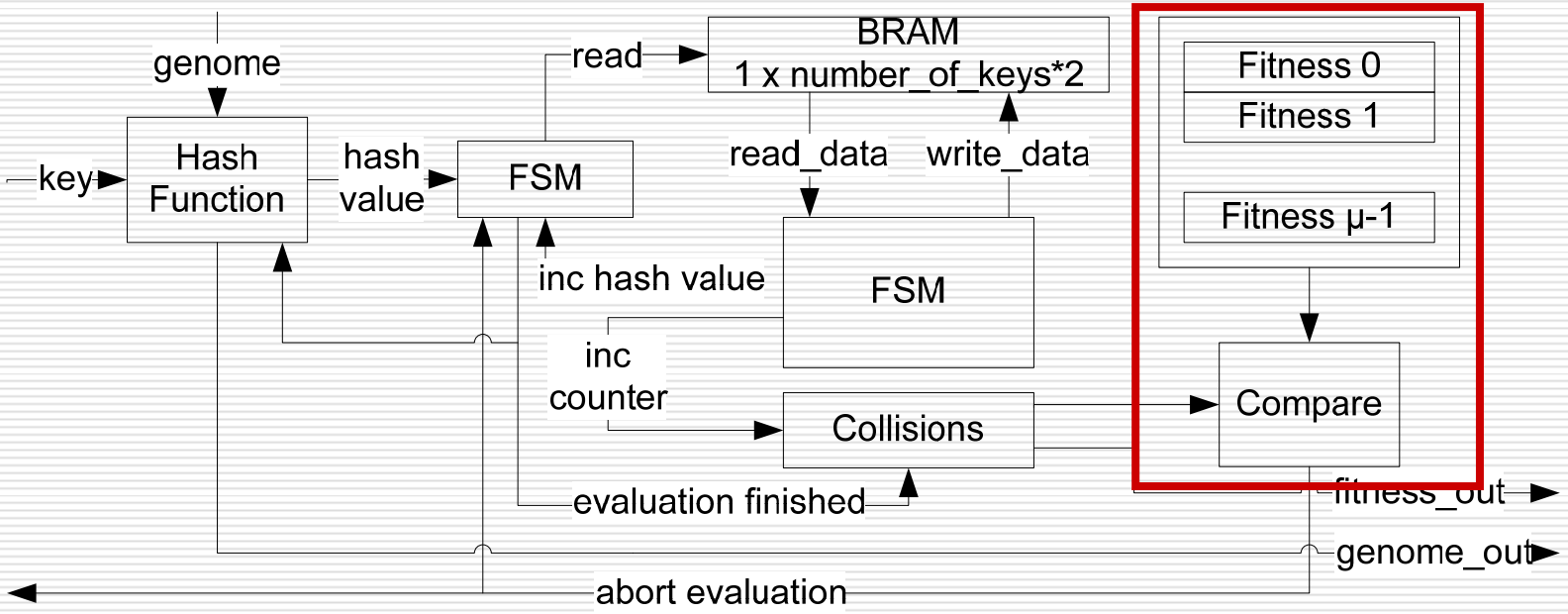
$$T_i = \sum_{j=1}^{k} \tau \cdot (1 + coll_j) \longrightarrow T = \sum_{i=1}^{\lambda} T_i + T_{reconf}$$

Fitness Evaluation - Speed



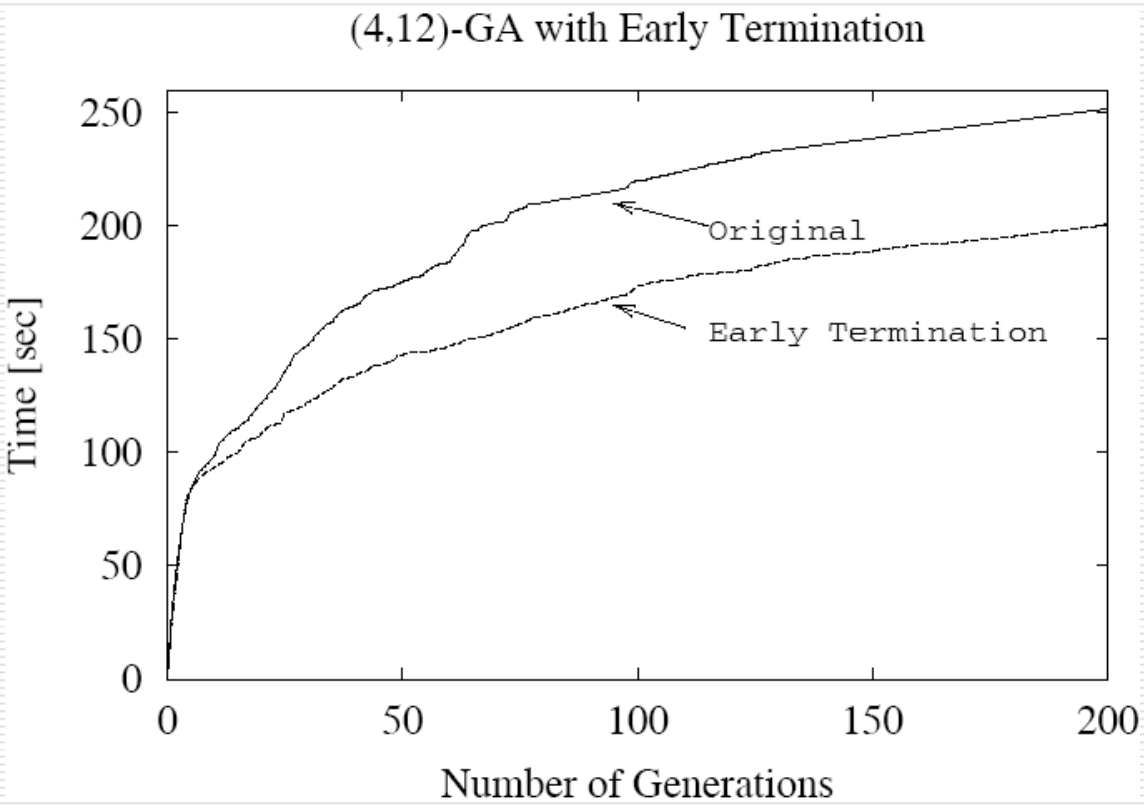
- Size:
  - 5416 slices
- Time:
  - 251 sec

Early Termination (ET)



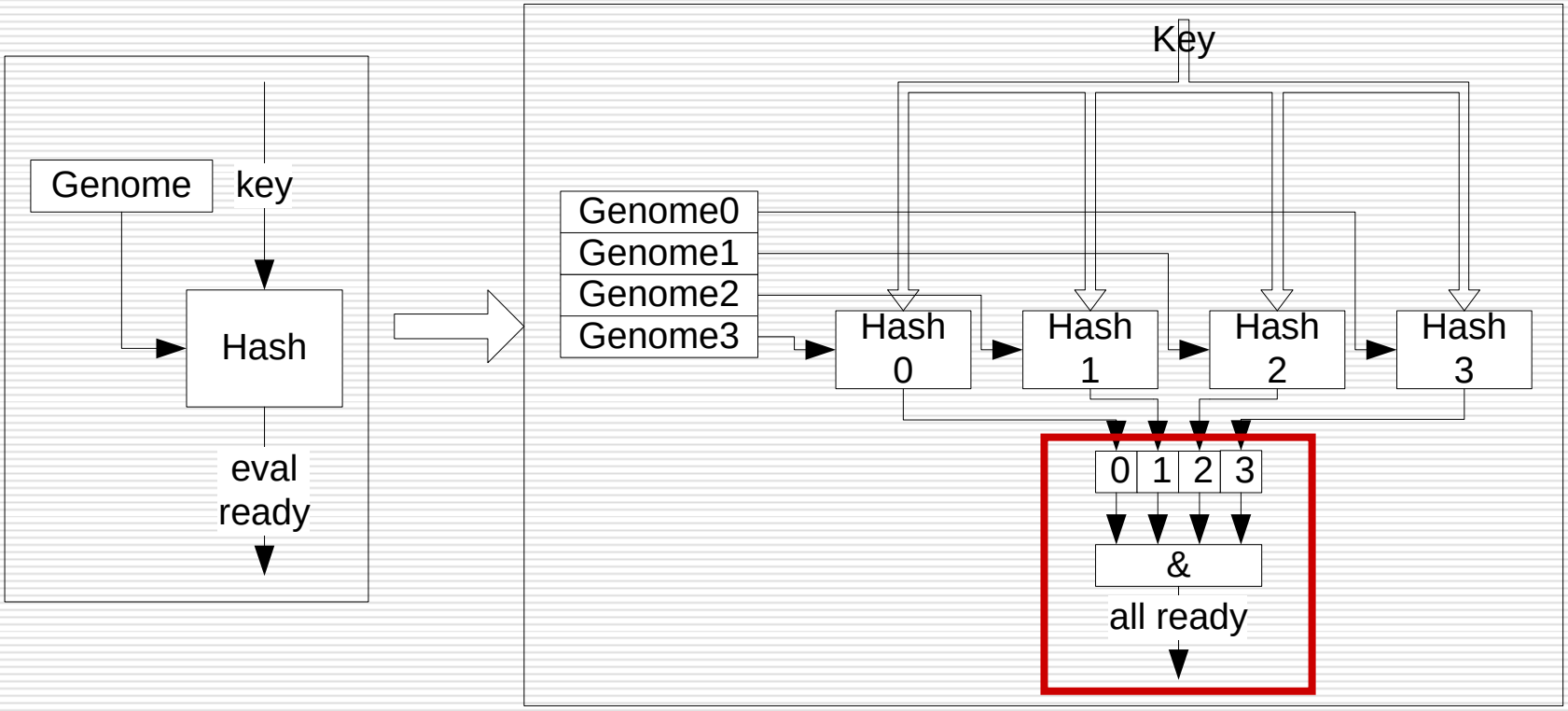
$$T = \sum_{i=0}^{\mu} T_i + T_{reconf} + (\lambda - \mu) \cdot T_{\mu}$$

Eearly Termination - Speed



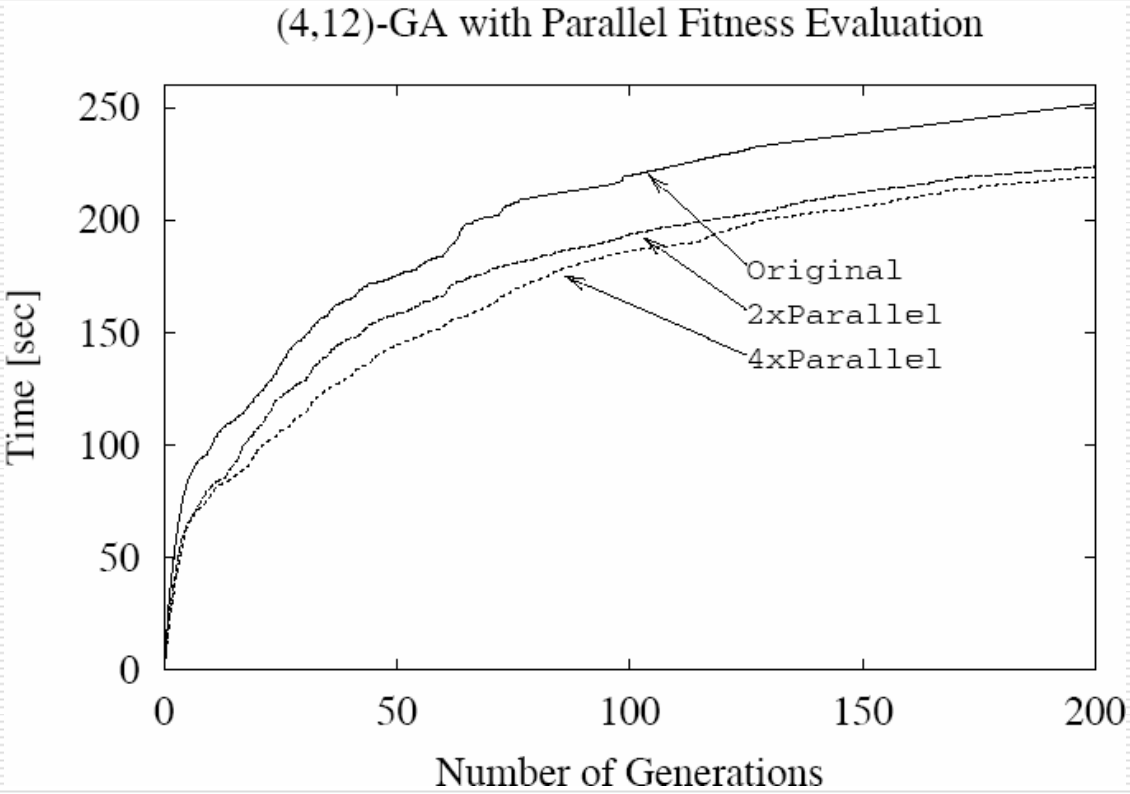
- Size:
  - 5592 slices
  - +3.35%
- Time:
  - 200 sec
  - +25%

Parallel Fitness Evaluation (PFE)



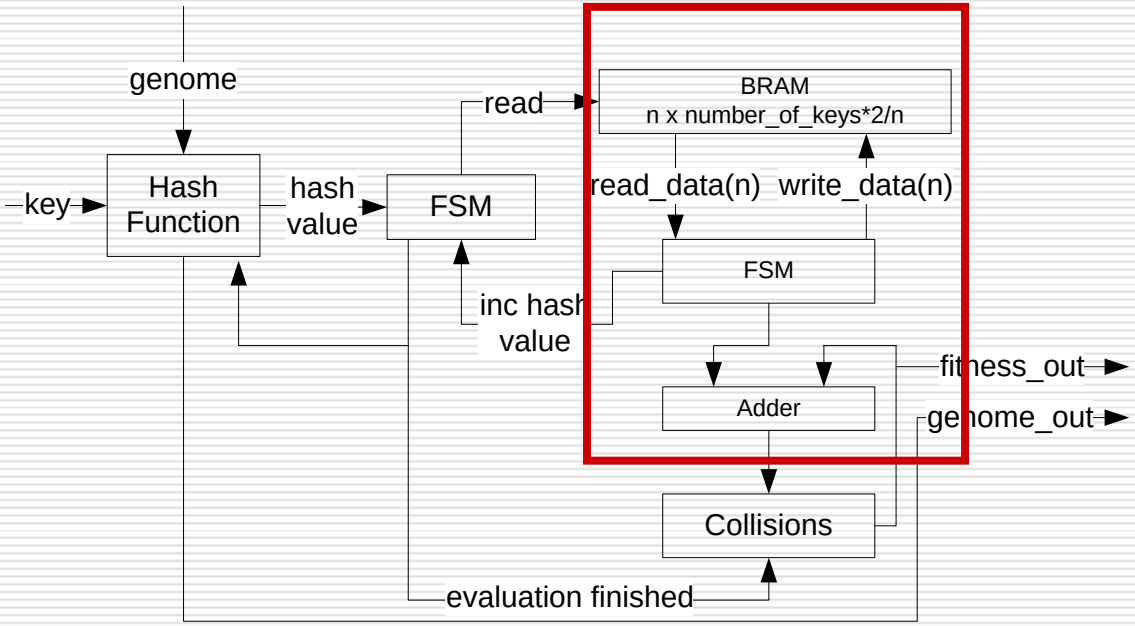
$$\sum_{i=1}^{k} \underset{j=1}{\overset{\lambda}{MAX}}(T_{i,j}) + T_{\mathrm{Re}conf}$$

Parallel Fitness Evaluation (PFE)



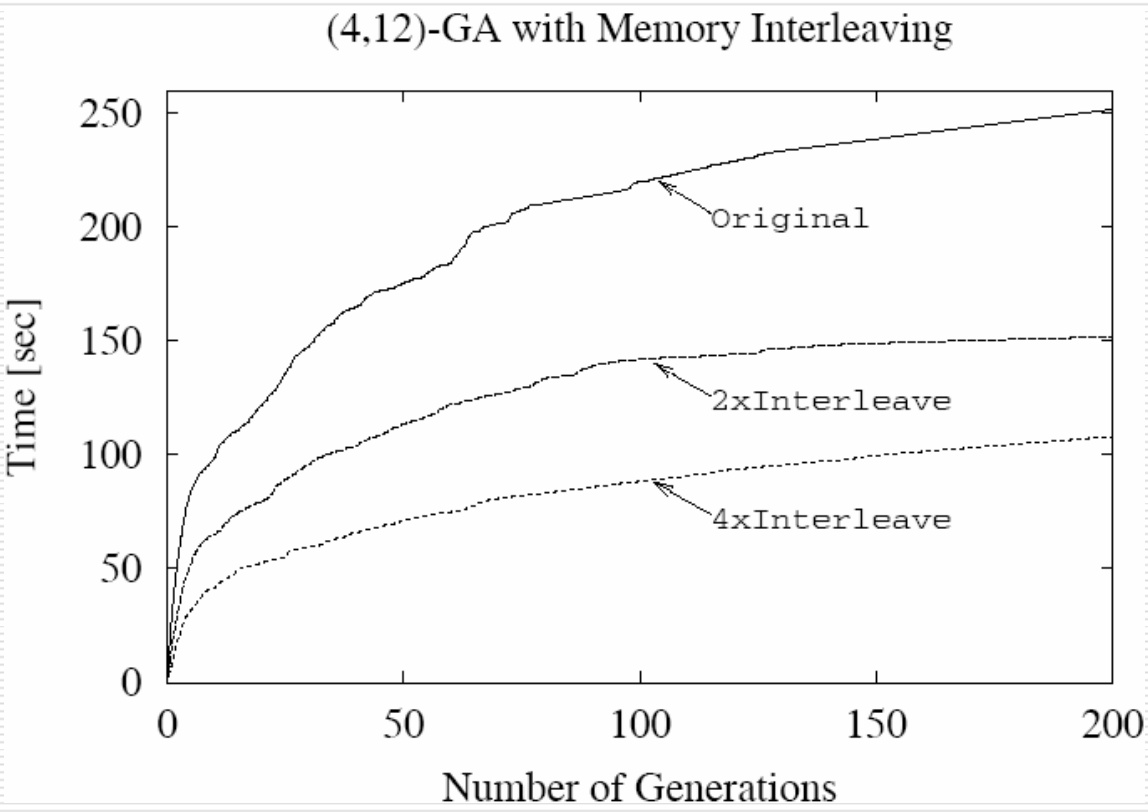
- Size (4x):
  - 7203 slices
  - +32.99%
- Time (4x):
  - 219 sec
  - +15%

Memory Interleaving (MI)



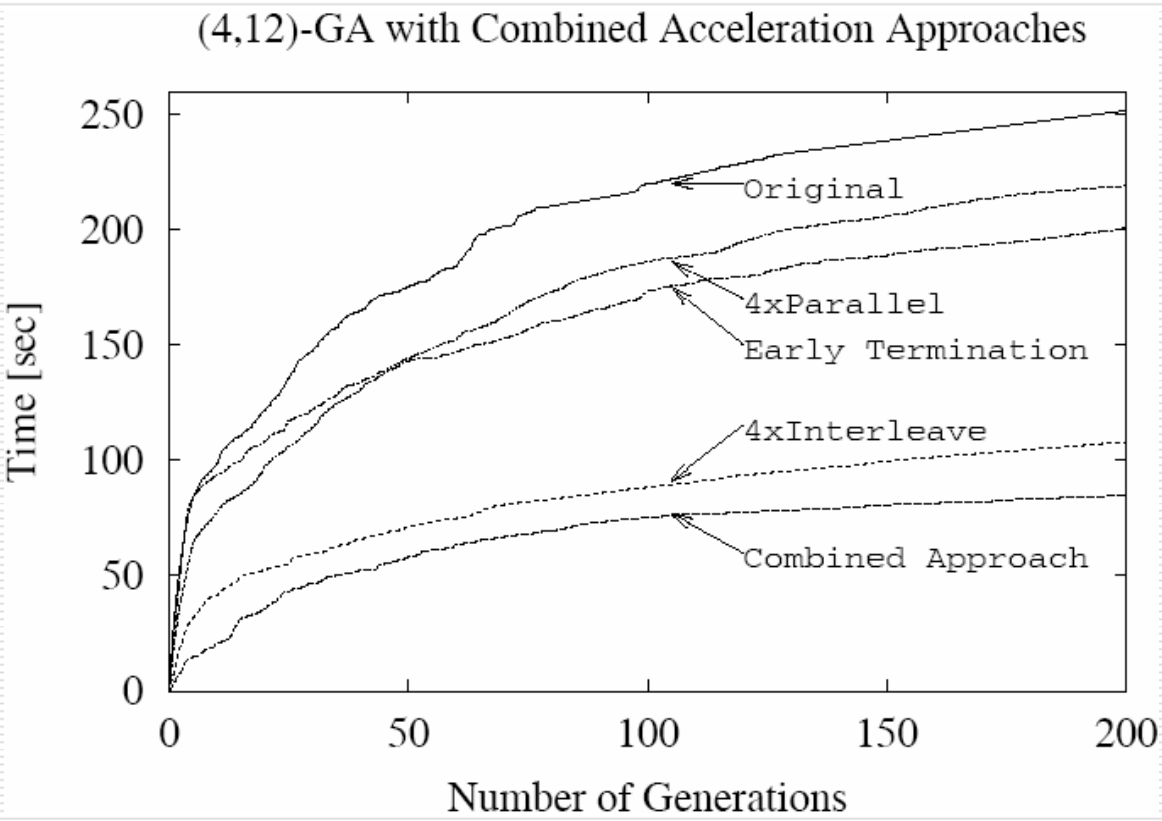
$$T_i^n = \sum_{j=1}^{k} \tau \cdot \left(1 + \left\lfloor \frac{coll_j}{n} \right\rfloor\right)$$

Memory Interleaving (MI)



- Size (4x):
  - 5572
  - +2.88%
- Time (4x)
  - 108 sec
  - +132%

Combination



- Size
  - 7473 slices
  - 37,98%
- Time
  - 85 sec
  - 230%

Synopsys

Module	Slices	Increase	Evolution Time [sec]	Speed Gain [%]
Original	5416	-	251	-
ET	5592	3.25	200	25
2xPFE	5945	9.77	223	12
4xPFE	7203	32.99	219	15
2xMI	5531	2.12	152	67
4xMI	5572	2.88	108	132
Comb	7473	37.98	85	230

Conclusion

- Working implementation of an evolvable Packet Classifier (7400 Slices, 125 MHz) with a real world performance of 10 million classifications per second
- Increase of evolution speed
  - Early Termination → 25%
  - Parallel Fitness Evaluation → 15%
  - Memory Interleaving → 132%
  - Combination → 230%
- Future Research:
  - Alternative architectures for hash functions
  - Adaptive fitness evaluation, and mutation rate
  - Cashing functionalities in the data path