Modulo Scheduling with Multiple II

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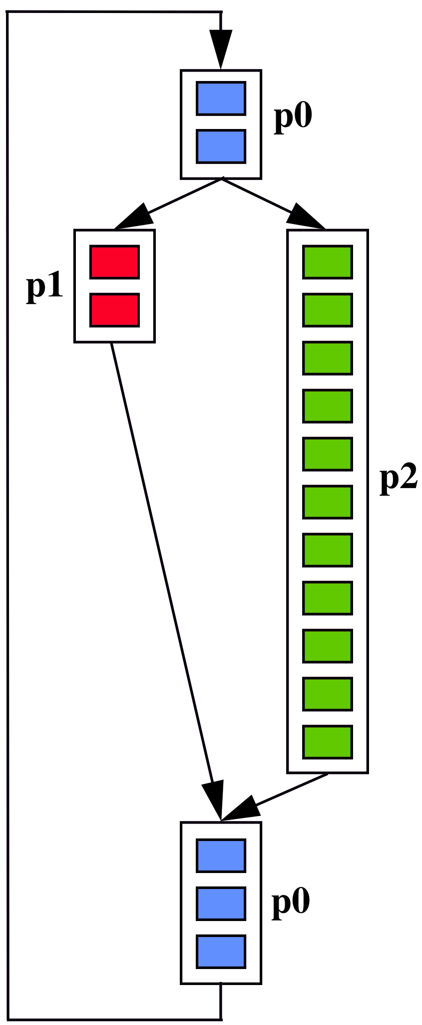
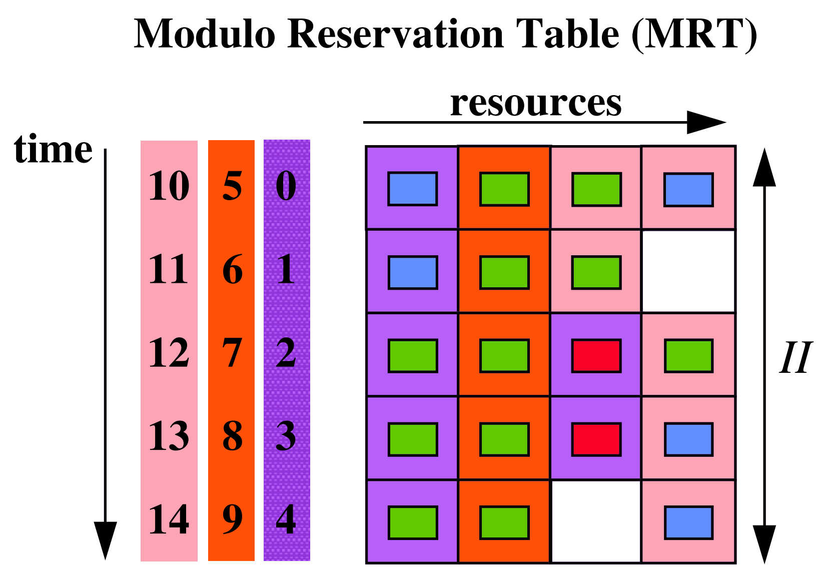
Motivation

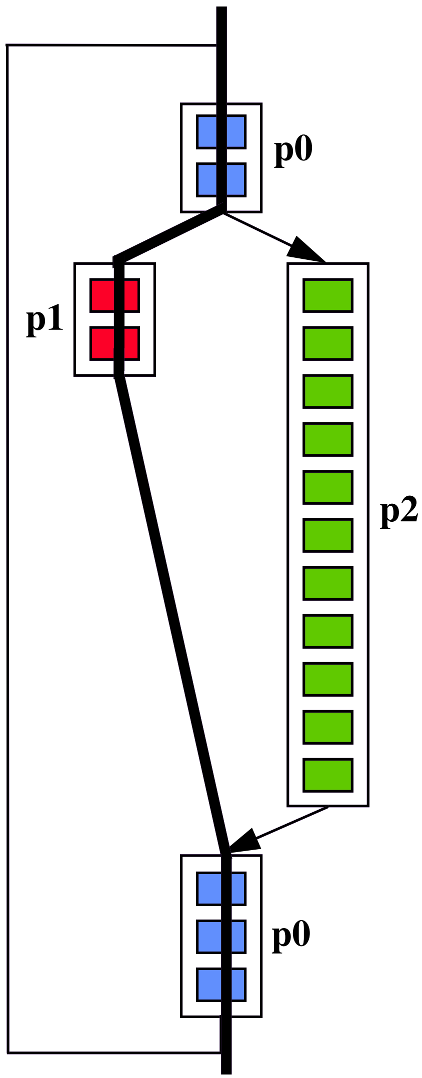
- Modulo scheduling is a powerful software pipelining technique
  - complex resources
  - low computational complexity
- Limitation: fixed length kernel
  - disadvantage for multi-path loops
- Multiple-II modulo scheduling
  - overcomes fixed length kernel constraints
  - assumptions: predicated execution and rot. reg. files

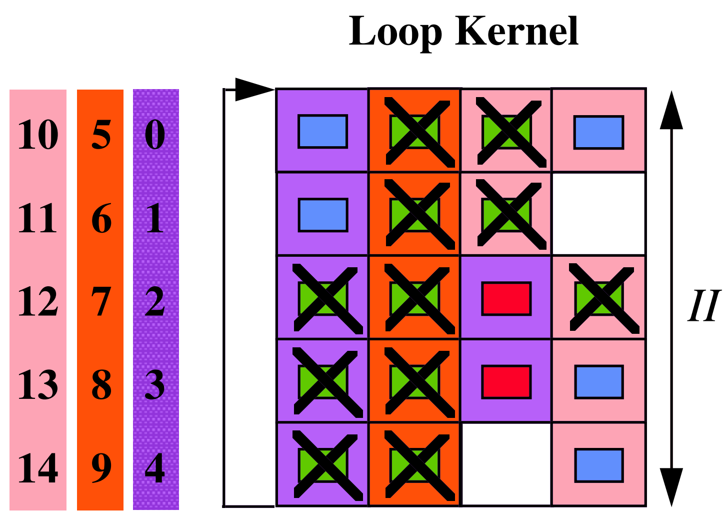
Modulo Scheduling



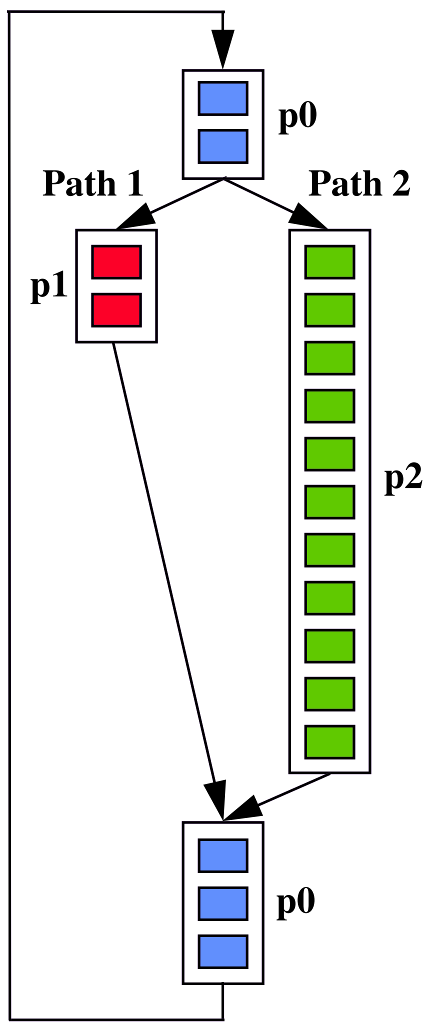


The Problem with Modulo Scheduling

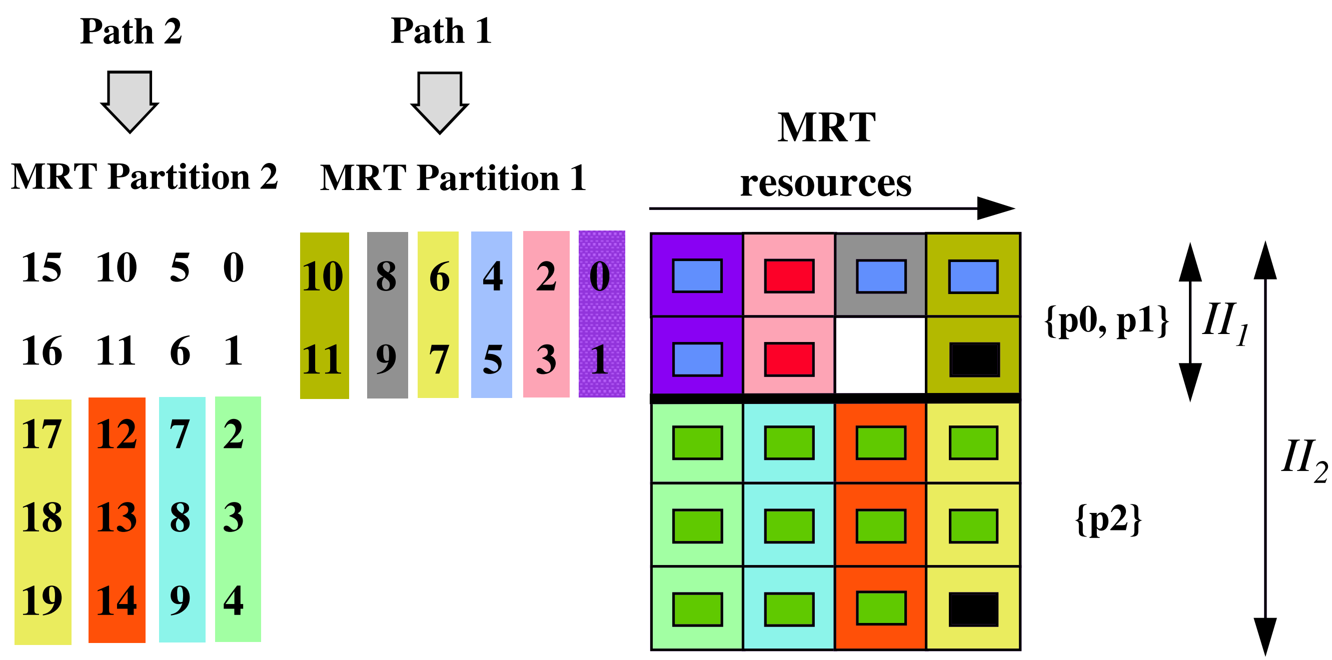




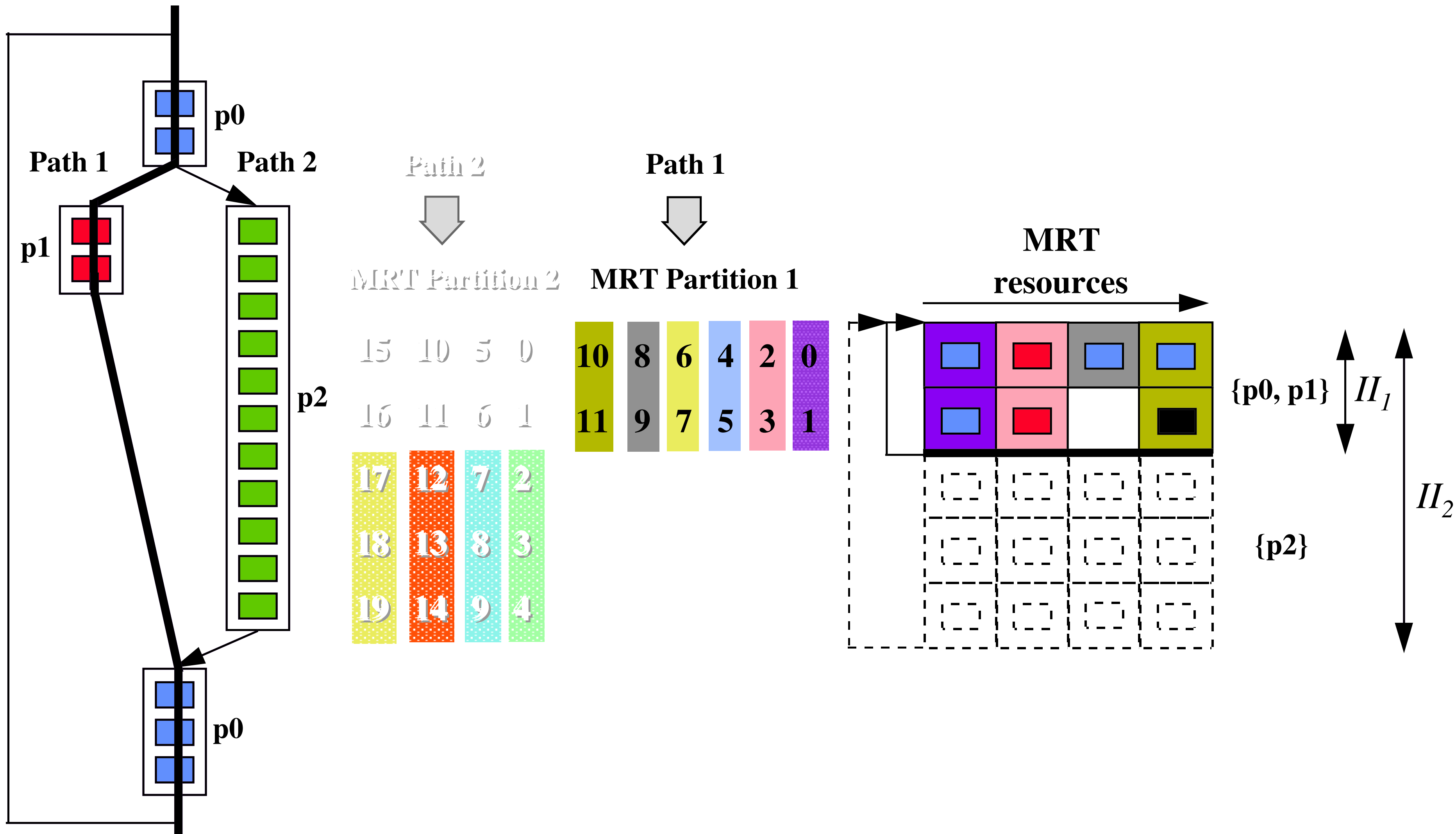
Proposed Solution
Multiple-II Modulo Scheduling



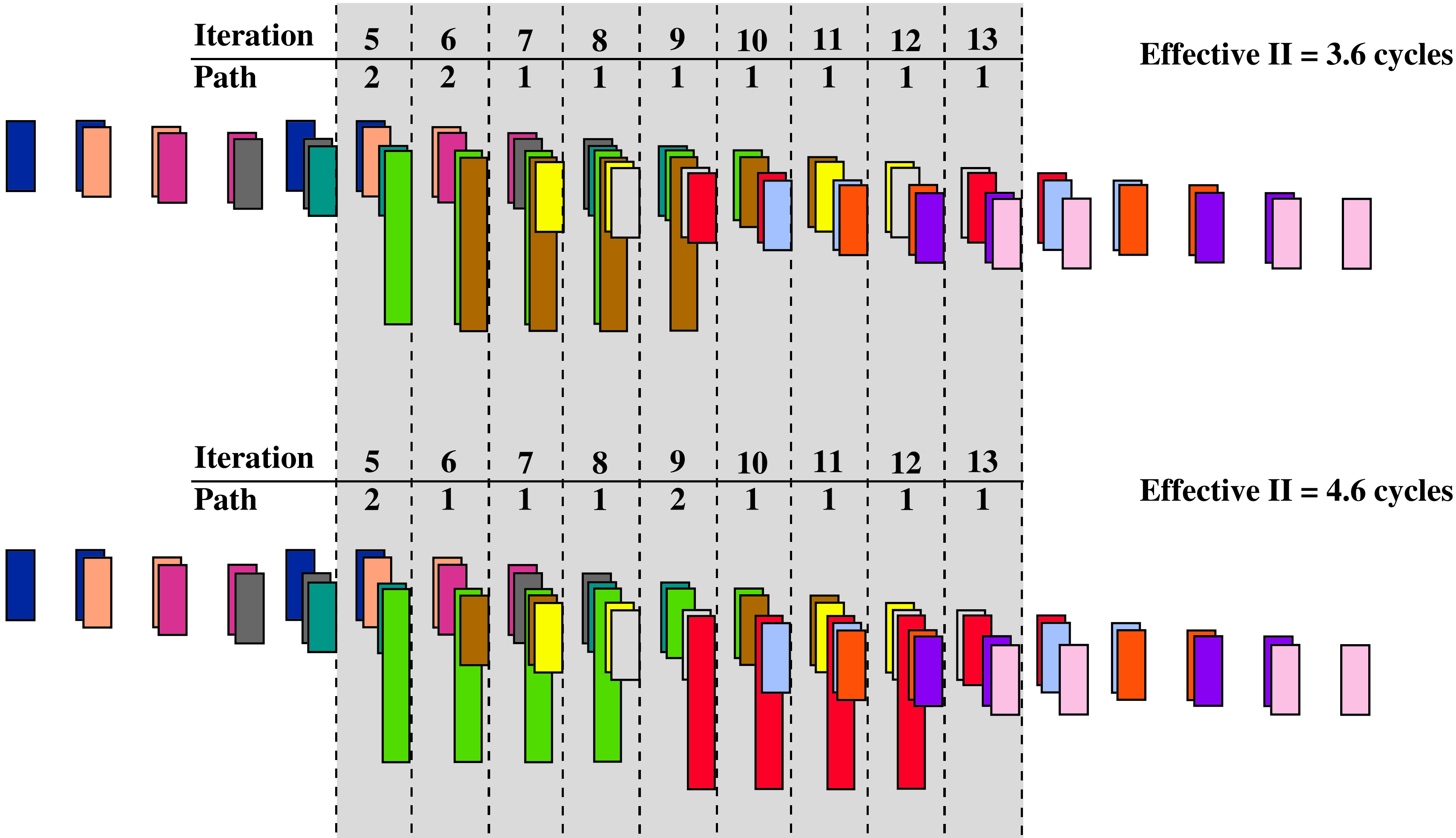
1- Partition MRT
2- Insert predicated loop back branch operations
3- Apply path sensitive operation scheduling



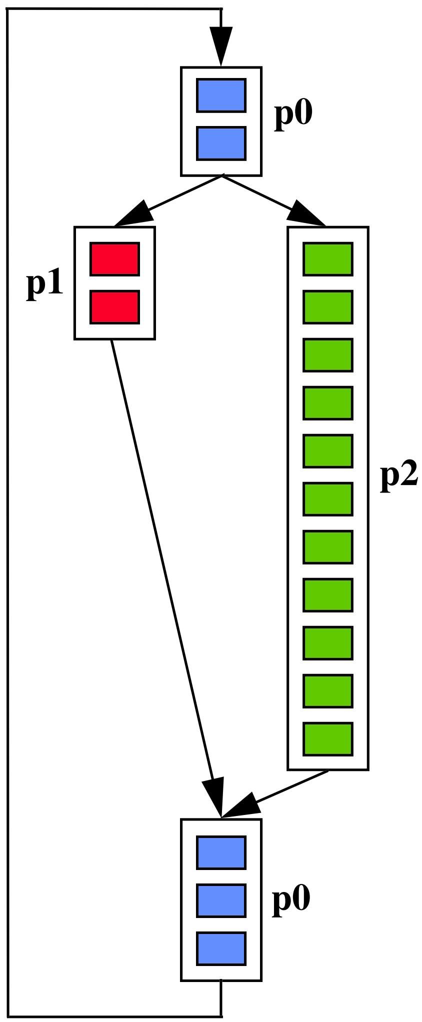
Advantage of Multiple-II Modulo Scheduling



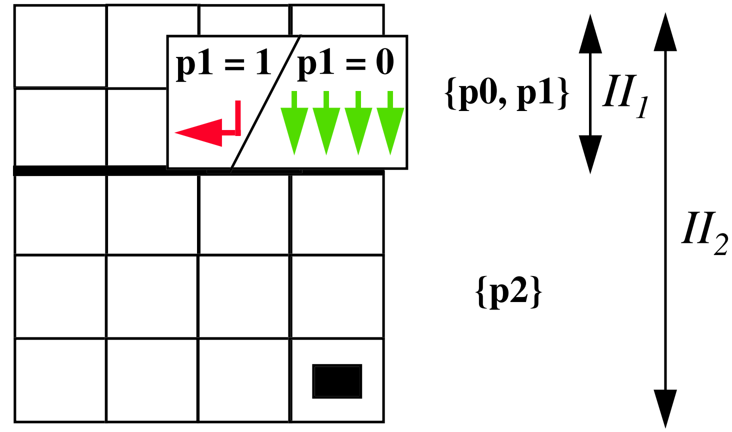
Effective II
Same Frequency Different Pattern



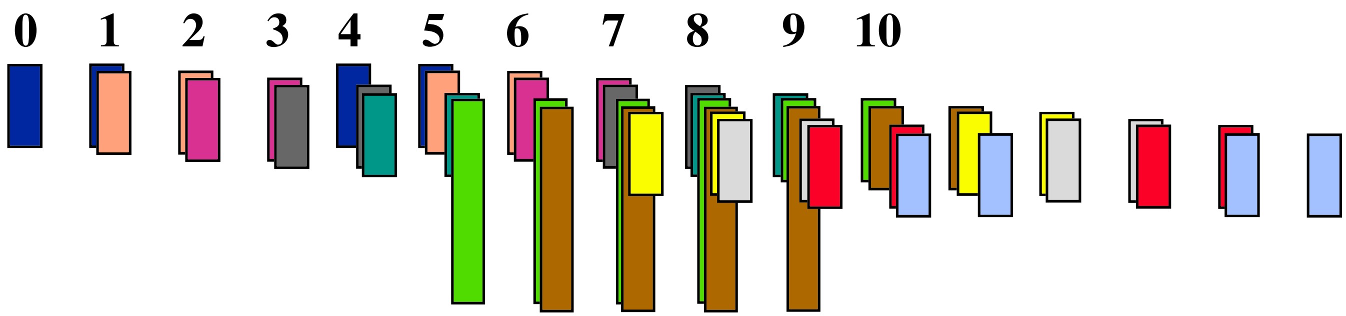
Loop Back Branch Predicate



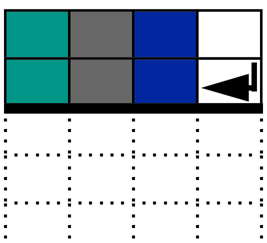
- Partition-1 Loop back branch predicated on p1
  - p1 set, loop back
  - p1 cleared, fall through
- Forced fall through (hardware)



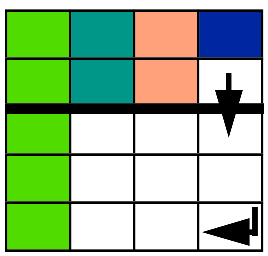
Transitions Between Partitions



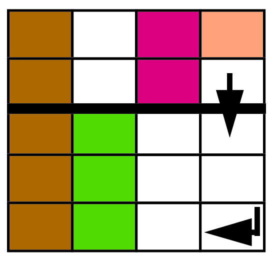
(4)
p1[1 1 1 1]
p2[0 0 0 0]



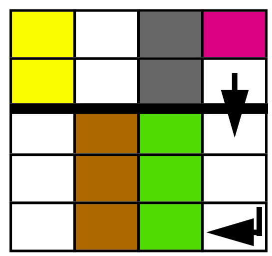
(5)
p1[0 1 1 1]
p2[1 0 0 0]



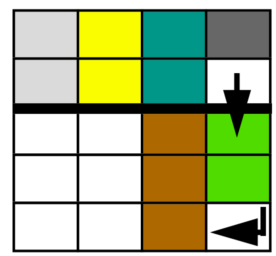
(6)
p1[0 0 1 1]
p2[1 1 0 0]



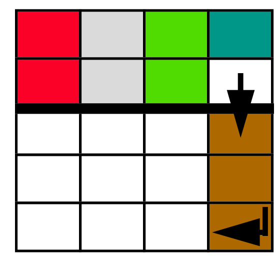
(7)
p1[1 0 0 1]
p2[0 1 1 0]



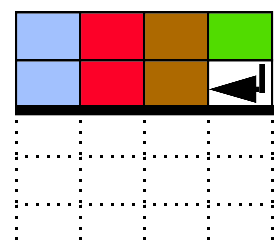
(8)
p1[1 1 0 0]
p2[0 0 1 1]



(9)
p1[1 1 1 0]
p2[0 0 0 1]



(10)
p1[1 1 1 1]
p2[0 0 0 0]

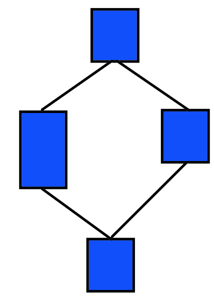


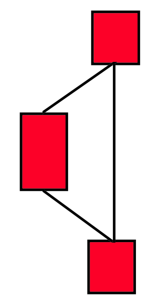
Experimental Results

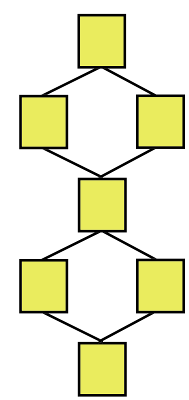
- Benchmarks
  - 18 loops from Perfect Club
- Heuristics
  - shortest path
  - most frequently executed path
- Machine model
  - superscalar RISC, issue-2, PE, rotating reg.

Experimental Results

Loop No.	Single-II	Heuristic 1: Shortest Path — Multiple-II	Heuristic 1: Shortest Path — % Difference	Heuristic 2: Most Frq. Executed Path — Multiple-II	Heuristic 2: Most Frq. Executed Path — % Difference
1	15	14.41	-4.09	14.41	-4.09
2	18	17.46	-3.09	17.46	-3.09
5	15	16	6.25	15	0.00
6	21	22	4.55	21	0.00
7	11	11.97	8.10	11.01	0.09
10	10	8.89	-12.49	8.89	-12.49
12	7	7	0.00	7	0.00
18	30	27	-11.11	27	-11.11
Average:			**-1.49**		**-3.84**
11	5	4.71	-6.16	4.71	-6.16
13	4	3.98	-0.50	3.98	-0.50
14	13	13.64	4.69	13	0.00
15	9	8.96	-0.45	8.96	-0.45
16	**9**	**6.69**	**-34.53**	**6.69**	**-34.53**
17	7	6.51	-7.53	6.48	-8.02
Average:			**-7.41**		**-8.28**
3	18	17.31	-3.99	17.31	-3.99
4	11	10.89	-1.01	10.89	-1.01
8	9	9.44	4.66	9.19	2.07
9	9	9.36	3.85	8.76	-2.74
Average:			**0.88**		**-1.42**

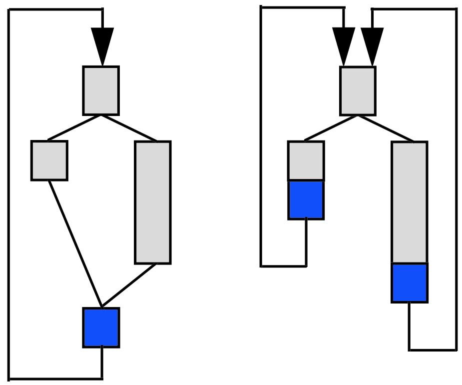






Future Work

- Implementation within IMPACT
  - optimizations
  - complex resources
  - loops with recurrences
  - architectures with no predicated support



- Compare to Enhanced Software Pipelining