Presentation Slides

Chapter 11

Pipeline Buffering

Logically Determined Design:

Clockless System Design With NULL Convention Logic

by Karl Fant

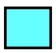
John Wiley & Sons, Inc.

Presents the effect of buffering cycles on pipeline throughput performance

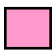
Buffering Cycles

Buffer cycles are cycles with a constant period that is the minimal period of all cycles in the system.

Placing buffer cycles between cycles with variable behavior can increase the throughput of a pipeline.

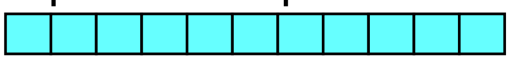


Cycle with period that varies from 1 to 5 with 1 being fast and 5 being slow

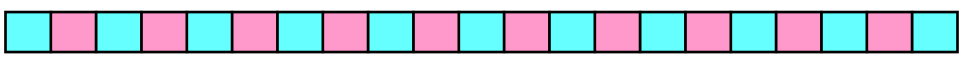


Cycle with constant period of 1

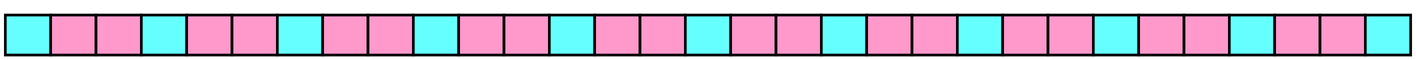
Pipeline composed entirely of cycles with varying period



Placing a single buffer cycle between each cycle with varying period will increse the throughput of the pipeline.

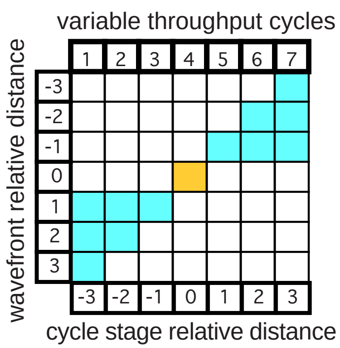


Placing two buffer cycles between each cycle with varying period will increse the throughput of the pipeline even more.

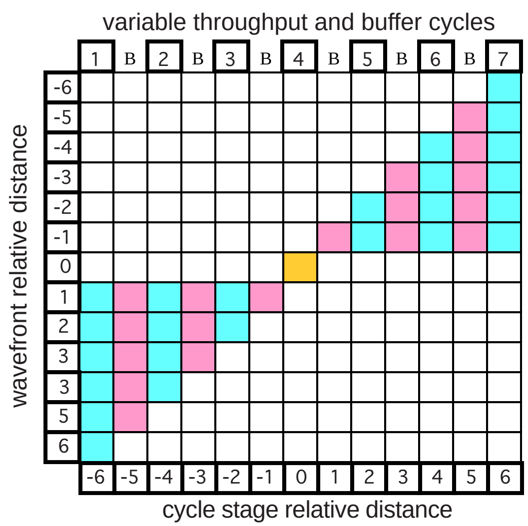


Buffering to Increase Throughput

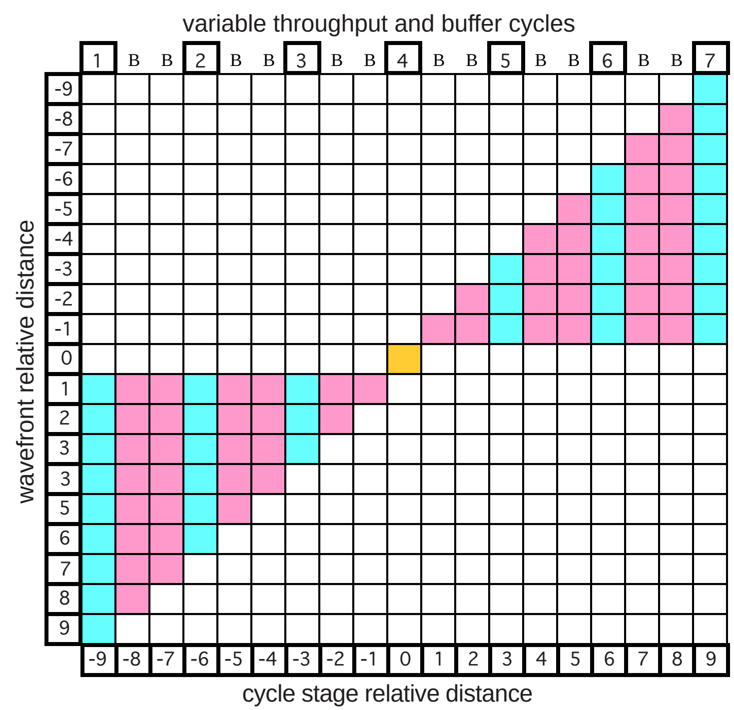
Buffer cycles (pink) make a pipeline longer without introducing more slow cycle delays. The effect of this is to increase shadow coverage between the variable throughput cycles (magenta) which makes it more likely that long cycle delays will shadow each other and lessen their overall effect on the pipeline throughput.



7 stage pipeline with no buffer cycles. Delay shadows 12 wavefronts.



13 stage pipeline with one buffer cycle between each variable cycle. Delay shadows 24 wavefronts.



19 stage pipeline with rwo buffer cycles between each variable cycle. Delay shadows 36 wavefronts.

The slow delay in the center (gold) projects its wavefront shadow right and up and its bubble shadow left and down.

Increased Throughput Buffer Structuring

The buffers should be placed in the pipeline for greatest effect.
This occurs when the shadow coverage is greatest.

pipeline cycle	1	2	3	4	5	6	7	8	9	10	11	
pipeline configuration	A	b	B	b	C	b	D	b	E	b	F	
variable cycle A	0		2		4		6		8		10	
variable cycle B	2		0		2		4		6		8	
variable cycle C	4		2		0		2		4		6	
variable cycle D	6		4		2		0		2		4	
variable cycle E	8		6		4		2		0		2	
variable cycle F	10		8		6		4		2		0	
total shadow coverage	30		22		18		18		22		30	= 140

a. distributed buffers

Interspersed buffers improve the throughtput.

pipeline cycle	1	2	3	4	5	6	7	8	9	10	11	
pipeline configuration	A	B	C	b	b	b	b	b	D	E	F	
variable cycle A	0	1	2						8	9	10	
variable cycle B	1	0	1						7	8	9	
variable cycle C	2	1	0						6	7	8	
variable cycle D	8	7	6						0	1	2	
variable cycle E	9	8	7						1	0	1	
variable cycle F	10	9	8						2	1	0	
total shadow coverage	30	26	24						24	26	30	= 160

b. center grouped buffers

But buffers bunched in the middle of the variable cycles provide the maximal shadow coverage and the optimal improvement of throughput.

pipeline cycle	1	2	3	4	5	6	7	8	9	10	11	
pipeline configuration	b	b	A	B	C	D	E	F	b	b	b	
variable cycle A			0	1	2	3	4	5				
variable cycle B			1	0	1	2	3	4				
variable cycle C			2	1	0	1	2	3				
variable cycle D			3	2	1	0	1	2				
variable cycle E			4	3	2	1	0	1				
variable cycle F			5	4	3	2	1	0				
total shadow coverage			15	11	9	9	11	15				= 70

c. edge grouped buffers

Buffers that do not separate the variable cycles have no effect at all on throughput.

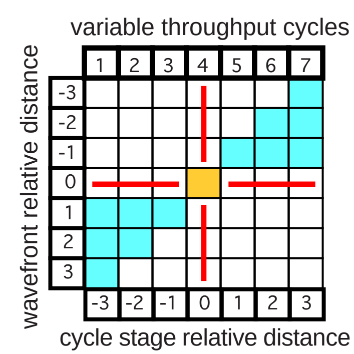
Increased Throughput Buffering

Buffering for optimal throughput works by increasing the physical pipeline distance between variable delay cycles and allowing long delays more opportunity to shadow each other lessening their affect on the throughput.

The distance is increased by adding buffer cycles that have periods shorter than or equal to the shortest period of the variable delay cycles.

Buffering to improve throughput is only effective when there is sufficient variability of delay behavior among the cycles. If the delay behavior of all cycles of a pipeline is constant then buffering will have no effect on the throughput. If long delays are rare they will likely not shadow and buffering will have little or no effect.

Whether two long delays shadow each other or not depends on the absolute value of the separation slope between them. The separation slope is how many wavefronts apart they are over how many cycles apart they are. If this ratio is less than or equal to 1.0 then they shadow each other. If it is greater than 1.0 then they do not shadow each other.



The farther apart long delays are in terms of wavefronts the less likely they will shadow.

The farther apart long delays are in terms of cycles the more likely they will shadow.

While adding buffers may not increase the throughput of a pipeline adding buffers will never decrease its throughput. They will just increase the latency and energy.

Buffering for Constant Throughput

Looking back from a slow cycle, wavefronts with slightly faster periods than the slow cycle will slowly back up until they encounter a source cycle that can slow down to exactly match the throughput of the slow cycle. At this point stable flow will begin at the throughput of the slow cycle.

Looking forward from a slow cycle, bubbles with slightly faster periods than the slow cycle will slowly back up until they encounter a destination cycle that can slow down to exactly match the throughput of the slow cycle. At this point stable flow will begin at the throughput of the slow cycle.

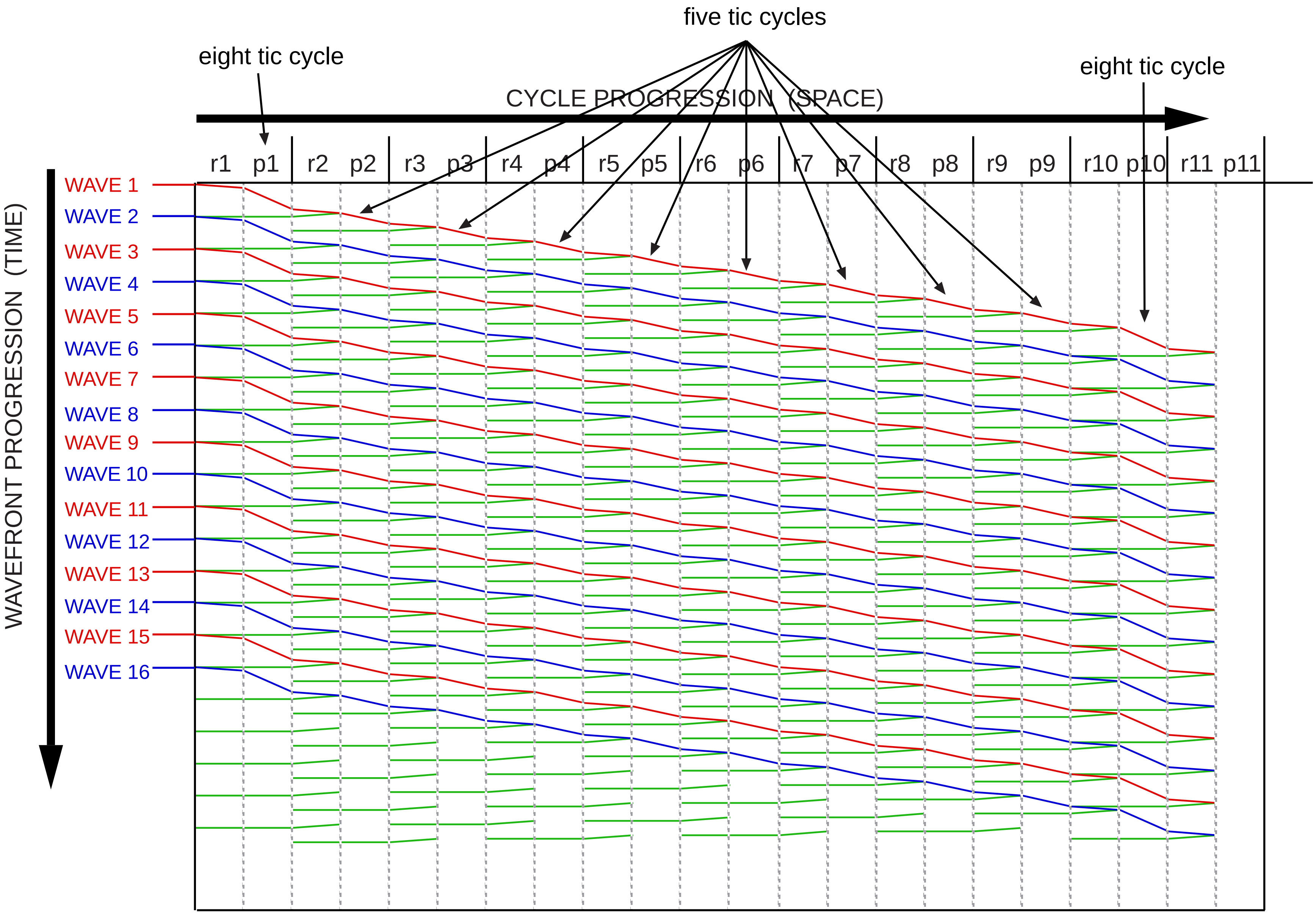
The Collective Shadow

A collective wait shadow is stored in the backed up wavefronts and bubbles. If the source cycle suddenly causes a long delay the shadow of the delay will be absorbed by the collective waits of the backed up wavefronts. If the slow cycle suddenly goes faster the shadow of the bubbles

The magnitude of this collective shadow depends on how much faster the fast cycles are than the slow cycle and how many wavefronts are backed up.

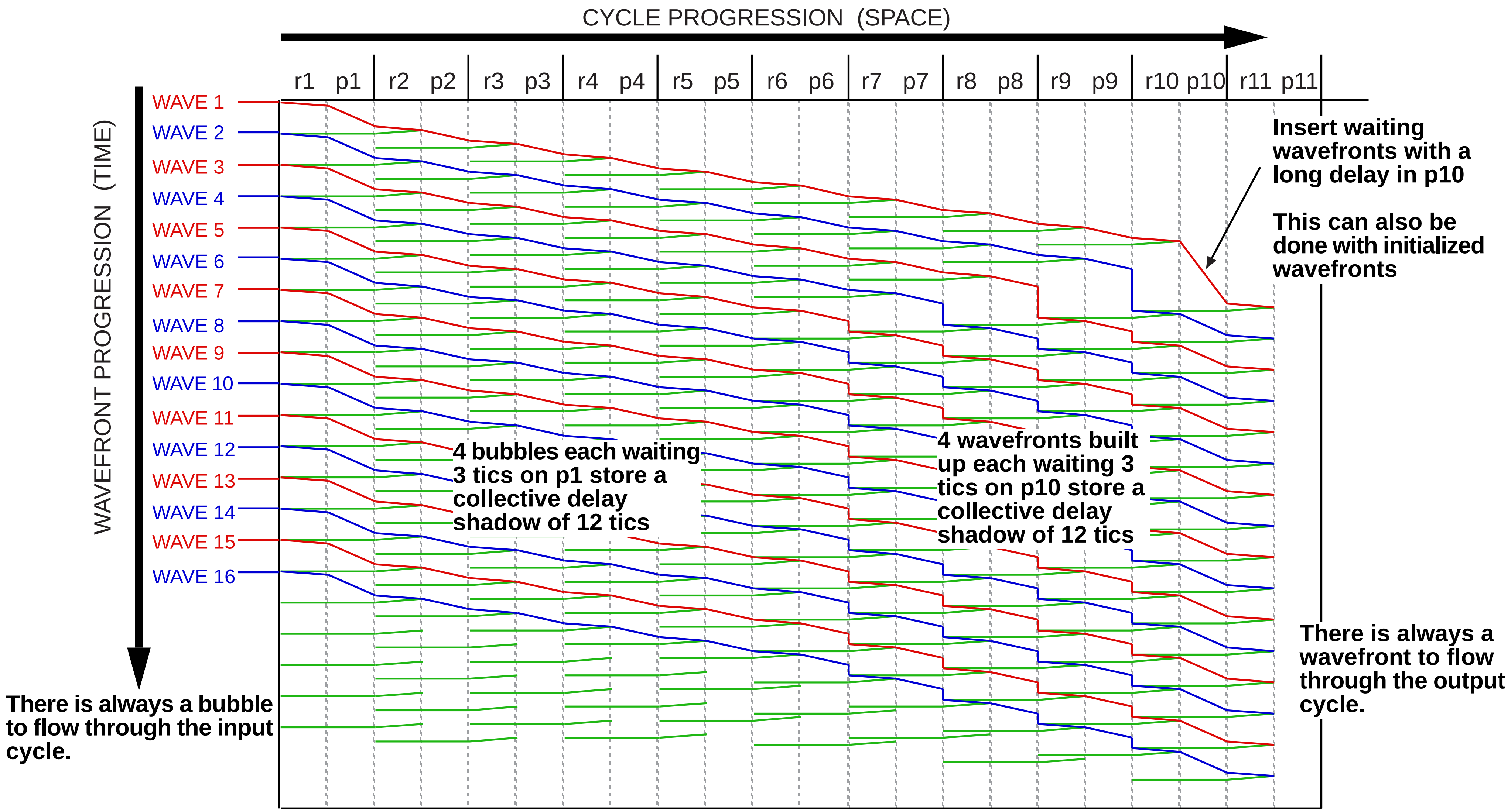
This collective shadow is the basis of buffering for constant throughput.

Baseline Cycle Structure



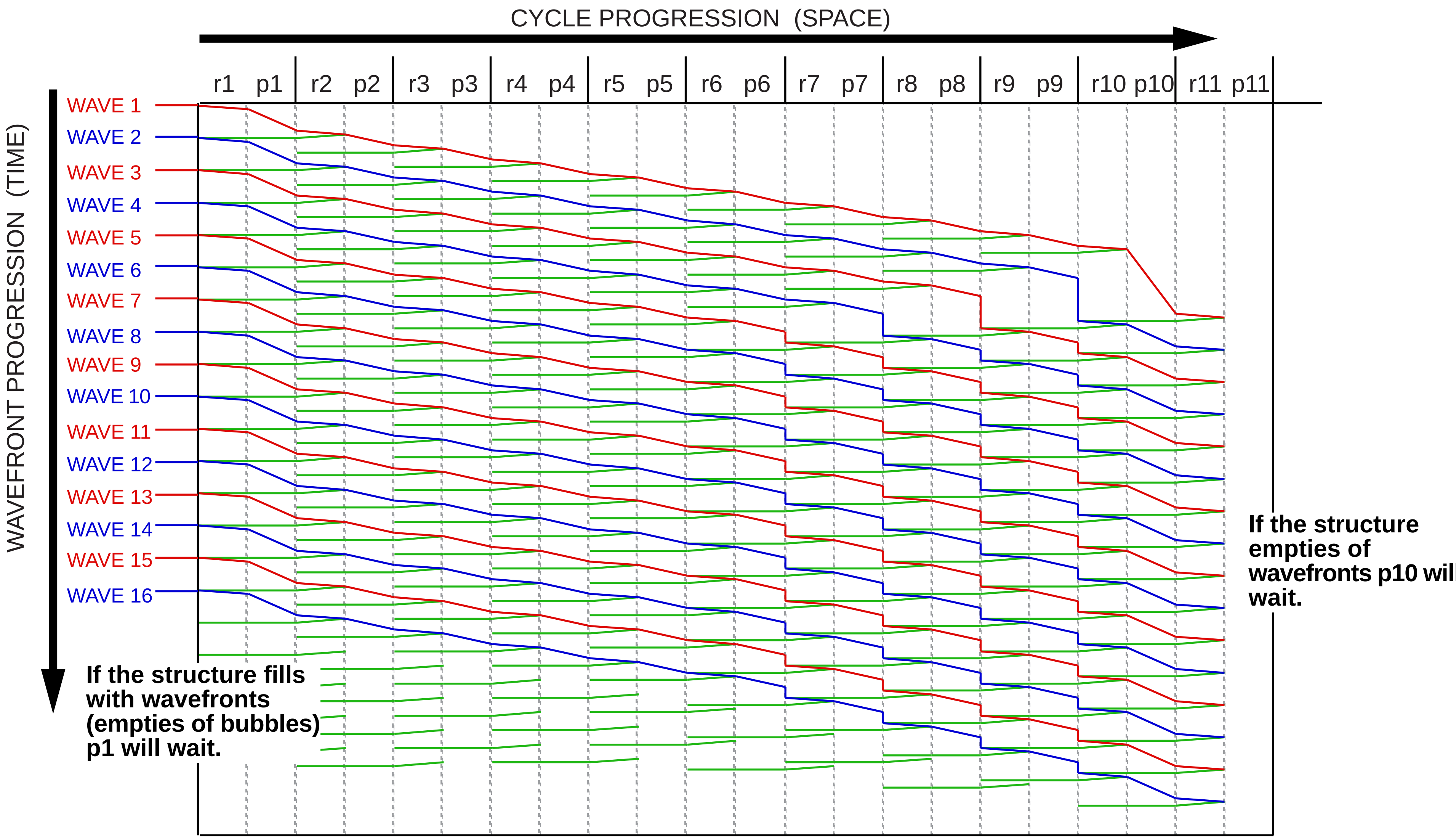
Eight faster cycles between two slower cycles.

Baseline Buffering Structure



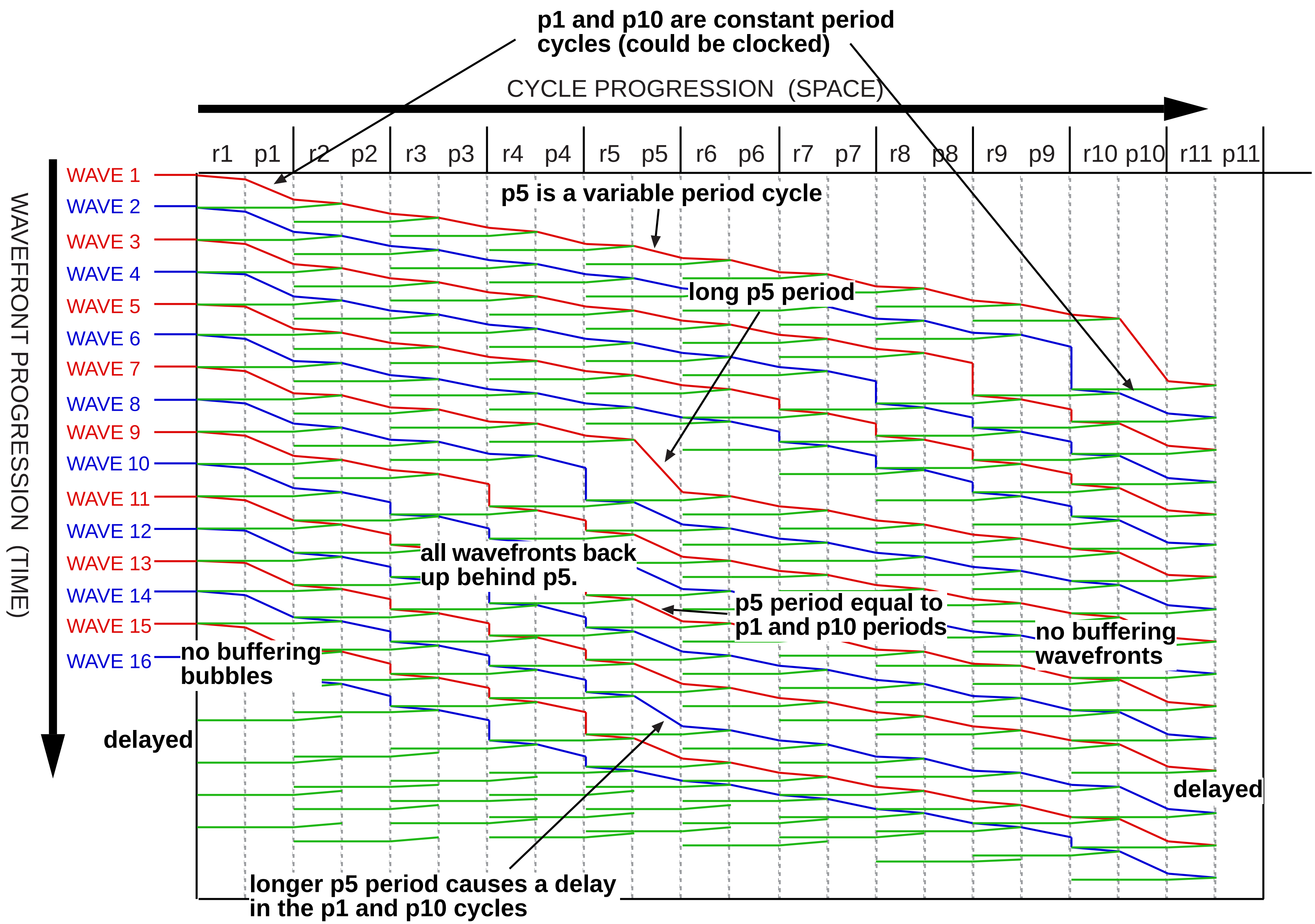
As long as cycles p1 and p10 cycle periods are equal there will always be 4 wavefronts between p1 and p10.

Variable Rate Boundary Cycles

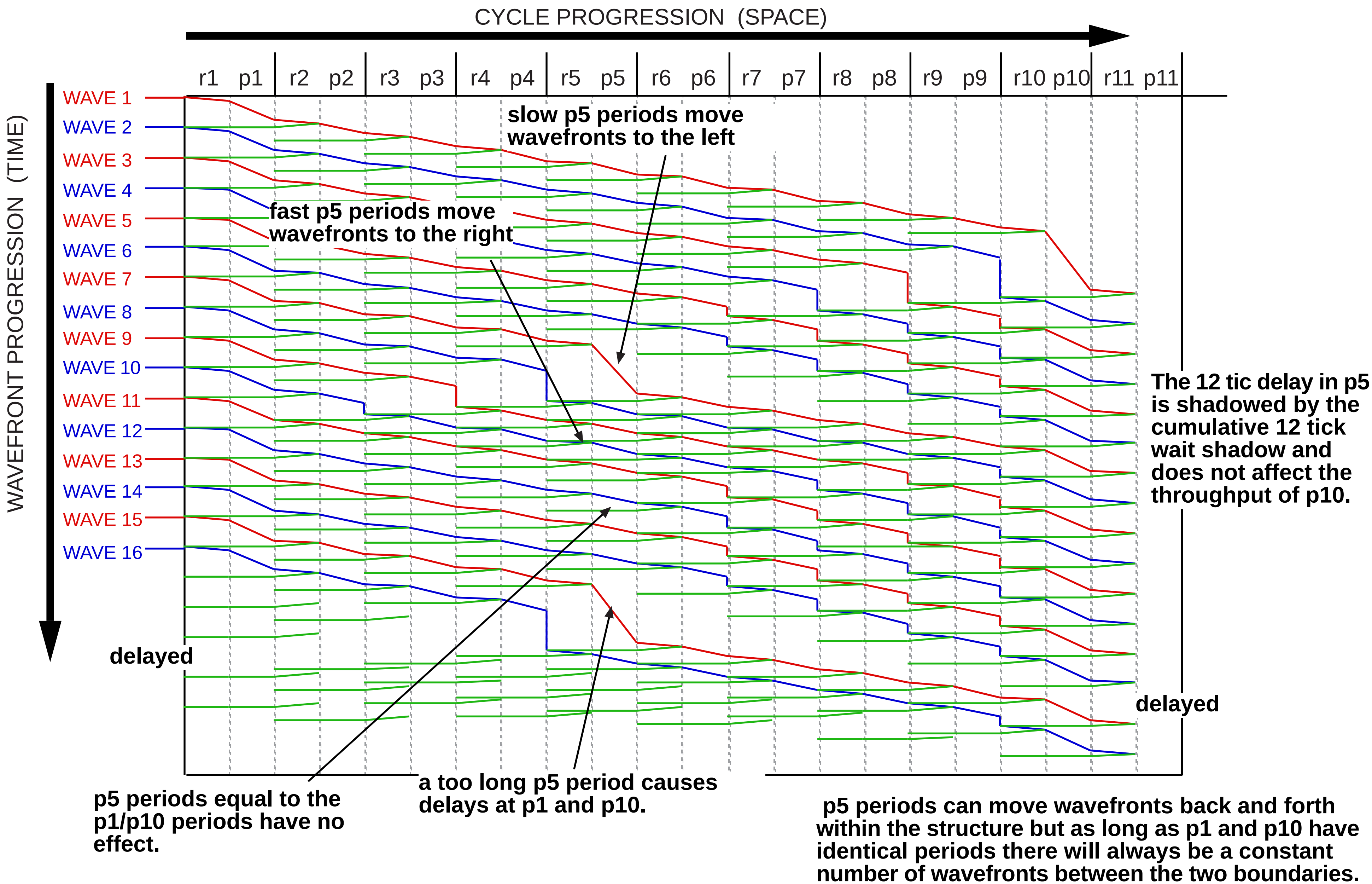


If p1 is slower than p10 wavefronts flow out of the structure.
If p1 is faster than p10 wavefronts flow into the structure.
The flow between p1 and p10 will be fully buffered until the structure either empties of wavefront or fills with wavefronts at which point p1 and p10 will encounter a wait.

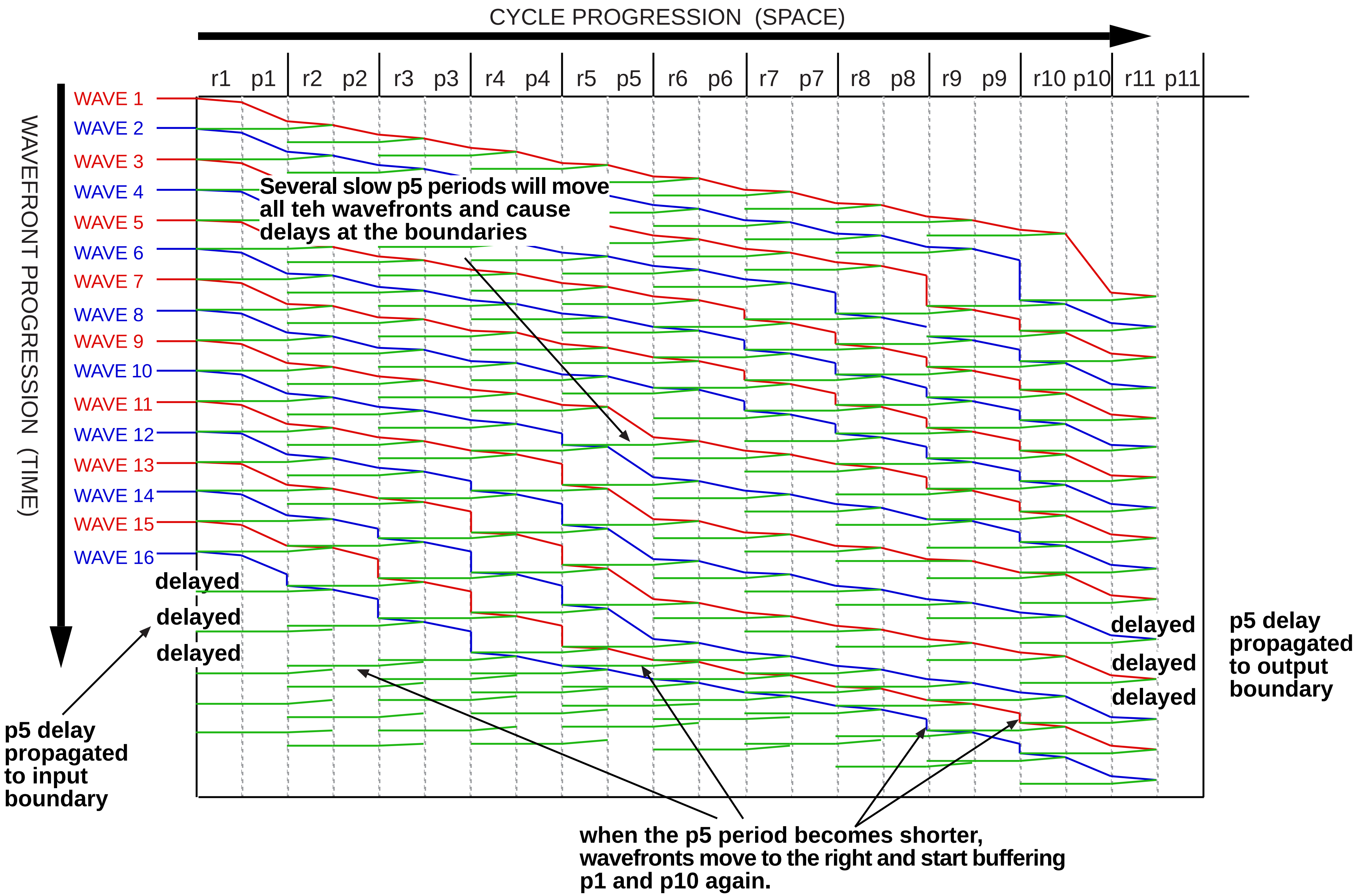
Buffering Variable Period Cycle Between Constant Period Cycles



Variable Period Buffering



Persistent Slow Periods



Buffering Summary

Increased Throughput buffering

Separate variable period cycles as far apart as possible with fast constant period cycles so that occasional long delays are more likely to shadow each other.

Variable cycle period buffering

Provide a captive population of wavefronts that project collective wavefront and bubble shadows. The captive population will ensure within an envelope of delay behavior that wavefronts are always presented to a receiving cycle and that bubbles are always presented to a sending cycle.

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