Verification of the FAIR Control System using Deterministic Network Calculus

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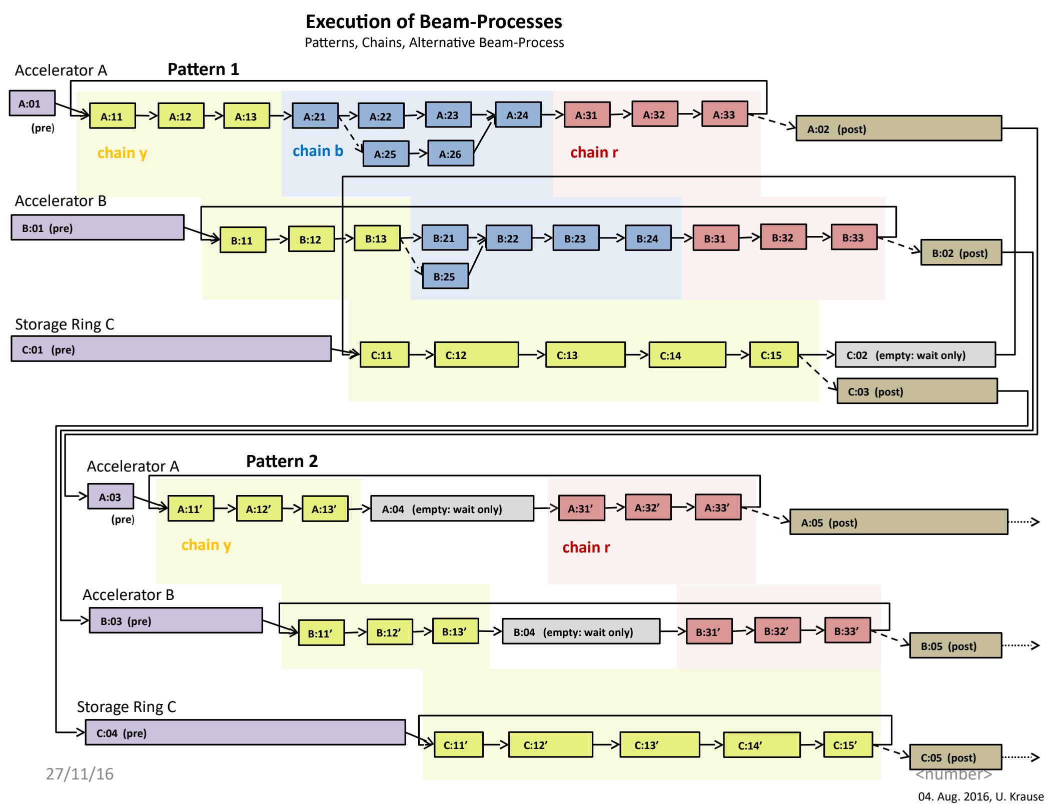
The FAIR Control System

- Non-deterministic message sequences
- Latency requirements: ≤ 500 µs

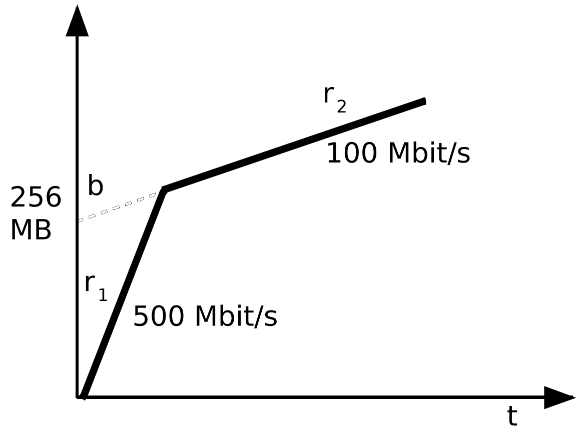


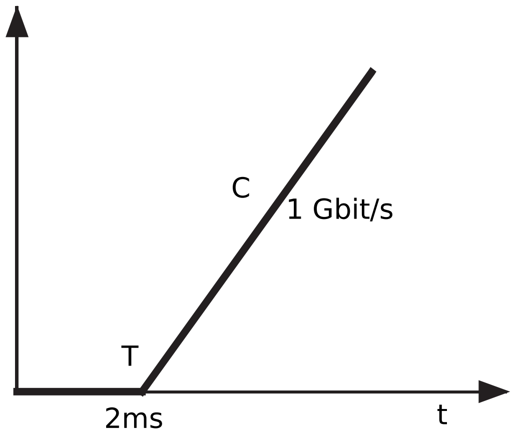
Deterministic Network Calculus

- Upper bounds on end-to-end delay, backlog
- Mathematical model of network
- Tools available: e.g. DiscoDNC

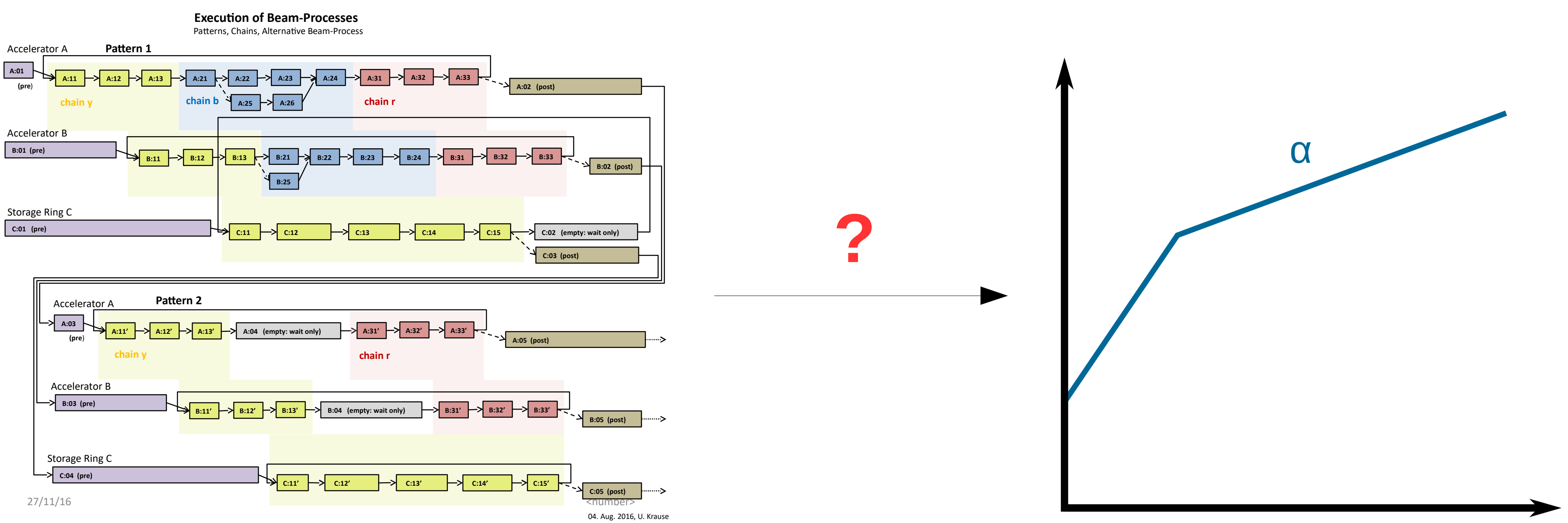
DNC – Core Concepts

- Arrival Curve
  - Upper bound on traffic entering the system in any given interval
- Service Curve
  - Lower bound on traffic leaving the system *while backlogged*
- Operators: Convolution, Deconvolution





Problem

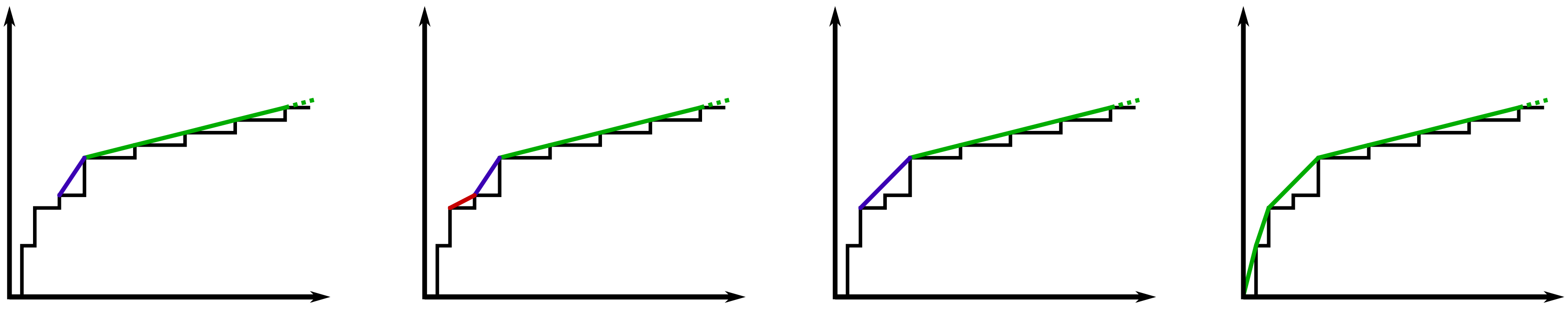

Execution of Beam-Processes
Patterns, Chains, Alternative Beam-Process
Accelerator A
Pattern 1
A:01 (pre)
A:11
A:12
A:13
A:21
A:22
A:23
A:24
A:25
A:26
A:31
A:32
A:33
A:02 (post)
chain y
chain b
chain r
Accelerator B
B:01 (pre)
B:11
B:12
B:13
B:21
B:22
B:23
B:24
B:25
B:31
B:32
B:33
B:02 (post)
Storage Ring C
C:01 (pre)
C:11
C:12
C:13
C:14
C:15
C:02 (empty: wait only)
C:03 (post)
Accelerator A
Pattern 2
A:03 (pre)
A:11'
A:12'
A:13'
A:04 (empty: wait only)
A:31'
A:32'
A:33'
A:05 (post)
chain y
chain r
Accelerator B
B:03 (pre)
B:11'
B:12'
B:13'
B:04 (empty: wait only)
B:31'
B:32'
B:33'
B:05 (post)
Storage Ring C
C:04 (pre)
C:11'
C:12'
C:13'
C:14'
C:15'
C:05 (post)
27/11/16
<number>
04. Aug. 2016, U. Krause
?
α

Approximating α

- α(i): consider all possible message sequences of length i
- α is sub-additive: $\alpha(k+i) \leq \alpha(k) + \alpha(i)$
- Sub-additive approximation: For some threshold k, $\alpha(nk+i) = n\alpha(k) + \alpha(i)$
  - Pseudo-periodic function with period k, increment α(k)

Concave Hull

- Affine segments with decreasing slopes
- "Backwards" approach: Start with final segment
- Slope of final segment: $\dfrac{\alpha(k)}{k}$



(a) (b) (c) (d)

Problem: Execution Time

- Specifications are nanosecond-accurate
- Brute force takes a lot of time and memory
- Exponential blow-up due to non-determinism

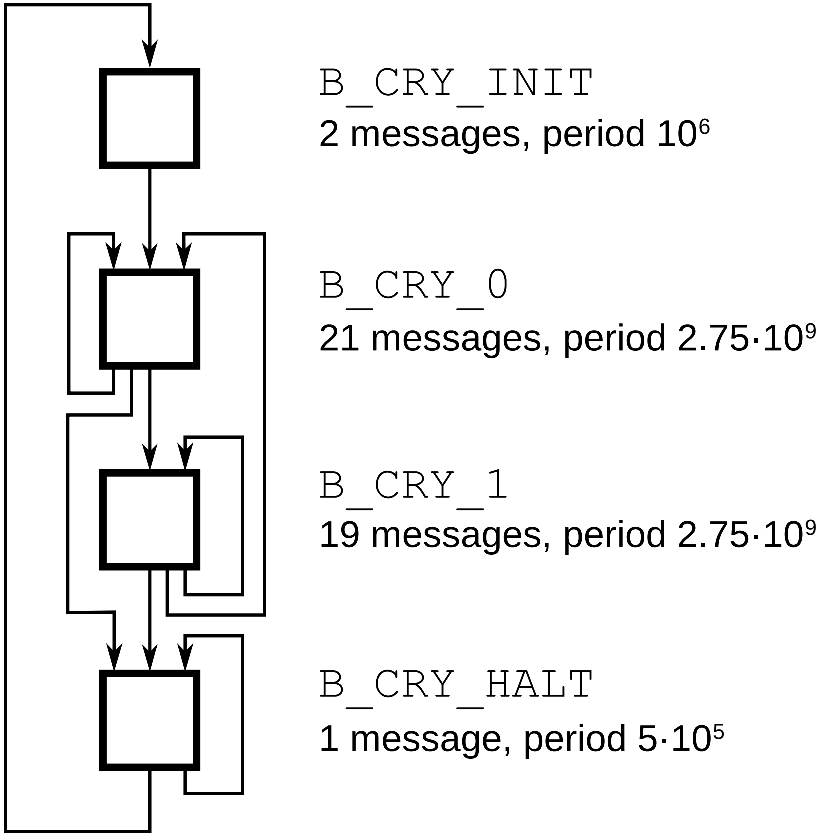
Counter Measures

- 10-100 messages per second
  - Sparse data structures
- Caching values
- Skipping intervals

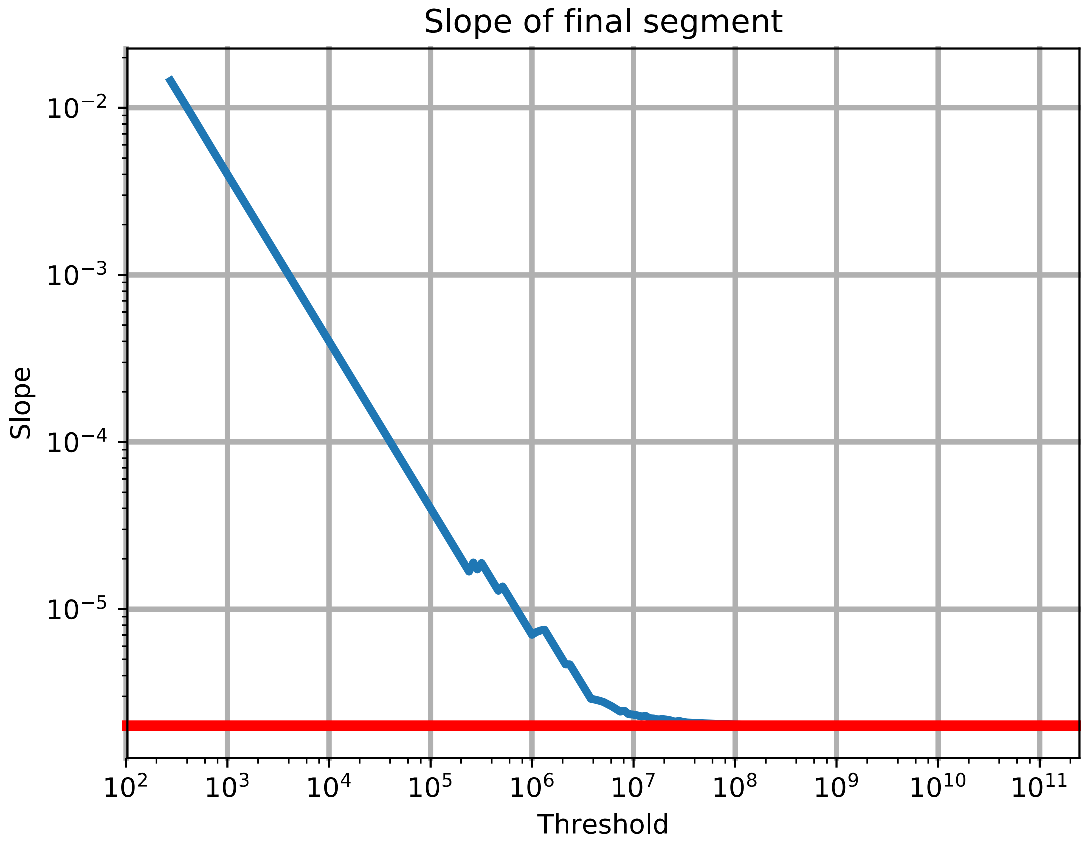
→ Theoretical runtime: $O\left(\left|B\right|^2 S \log S + \left|B\right| S^2 \log S\right)$

Evaluation

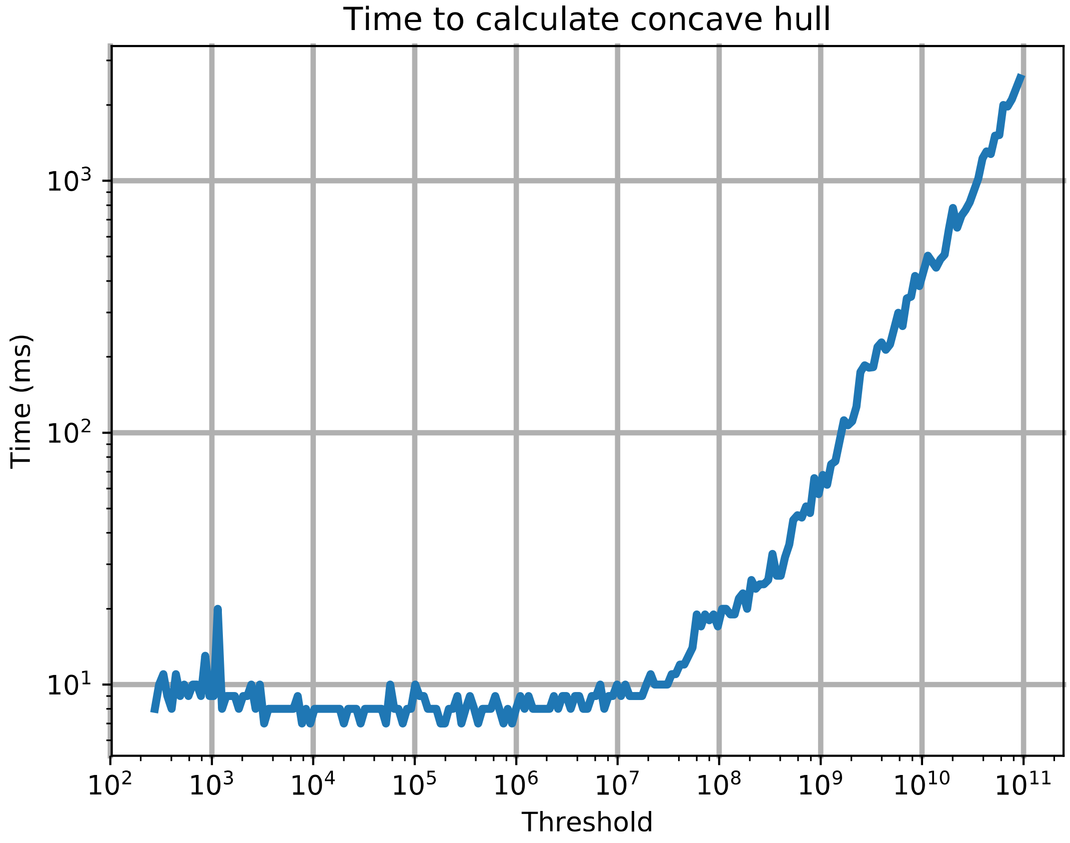
- With respect to threshold k
- Based on fictional, but representative specification



Evaluation: Accuracy



Evaluation: Time



Evaluation

Threshold	Slope	Time
10^6	$7 \cdot 10^{-2}$	8 ms
10^7	$2.3 \cdot 10^{-4}$	11 ms
10^8	$2.03 \cdot 10^{-6}$	17 ms
10^9	$2.003 \cdot 10^{-6}$	57 ms
10^{10}	$2.0003 \cdot 10^{-6}$	323 ms

Summary

- Reasonably memory efficient
- Fast enough for interactive use
- Good speed-accuracy trade-off
- Next steps:
  - Use arrival curve and model of network to derive delay bounds

Thank you for listening!