Dataflow Analysis Revisited

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'Knowing is not understanding.'
Charles Kettering

2 Acknowledgements

Joint work with:
- Marc Geilen
- Sander Stuijk
- AmirHossein Ghamarian
- Bart Theelen
- …

Projects:
- NWO PROMES
- EC FP6 Betsy
- EC FP7 MNEMEE

3 Overview

- Embedded Multi-media
- Analysis of Synchronous Dataflow Graphs
  - Throughput Analysis
  - Throughput-Storage Trade-off Analysis
  - Parametric Throughput Analysis
  - Scenario-aware Dataflow
- Multiprocessor System-on-Chip Design
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4 Embedded Multi-media

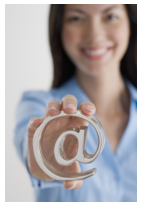
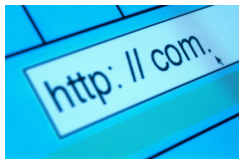
Trends
Concurrency
Connectedness
Interaction
Variability

emb. mm → throughput → storage → parameters → scenarios → mpsocs → the future

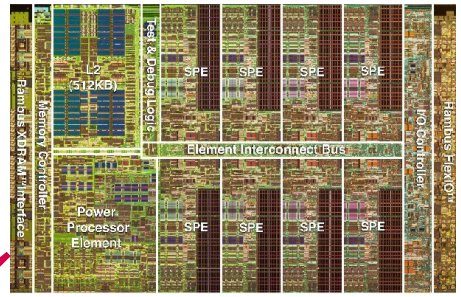
5 Embedded Multi-media

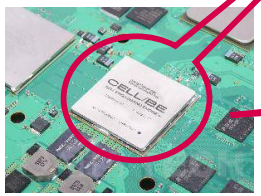
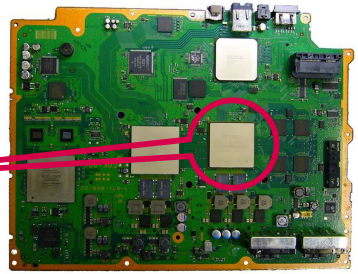




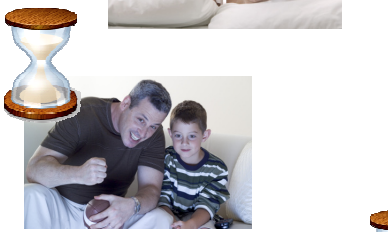
6 Embedded Multi-media

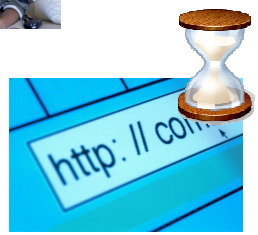



7 Embedded Multi-media

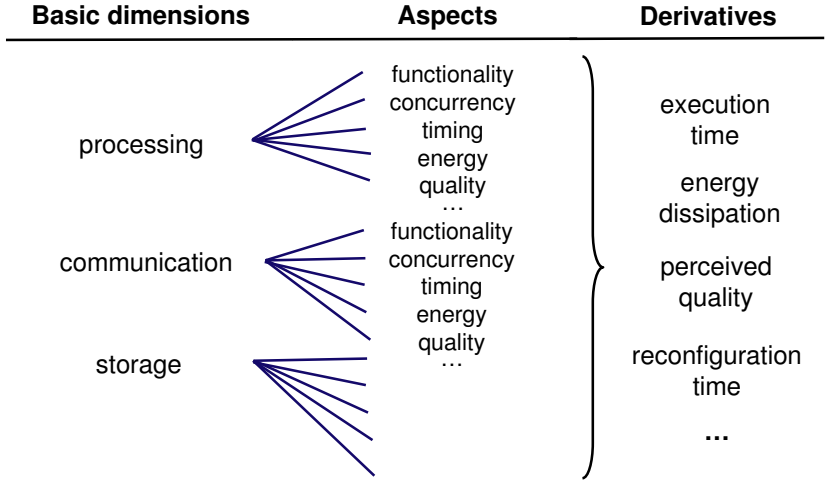




8 Approach: Models of Computation (MoCs)

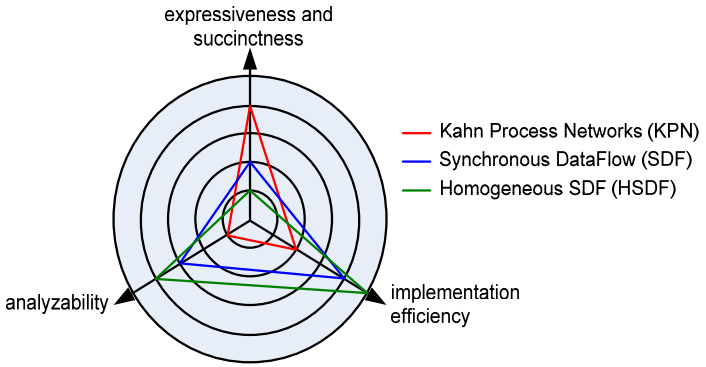
on the interface between science and engineering | essential for predictability



9 Essential Challenges

predictability and efficiency

… are contradictory



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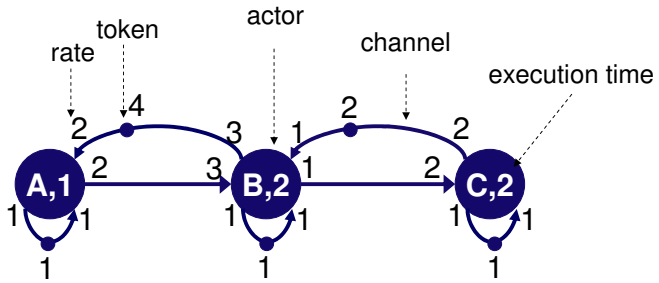
11 Synchronous Data Flow Graphs

(SDFGs [Lee 1986])

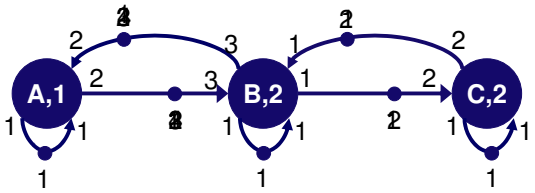


Throughput: average number of actor firings over time

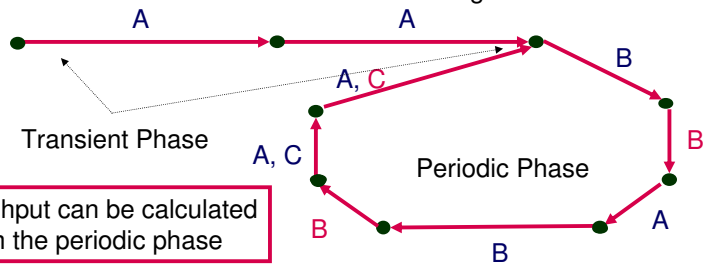
12 Self-timed Execution

- Each actor fires as soon as it can fire
- Known to maximize throughput

13 Our Throughput Analysis Method



State: distribution of tokens + remaining execution times



Throughput can be calculated from the periodic phase

Efficient implementation
Consider a subset of the firings of one actor only to detect a recurrent state

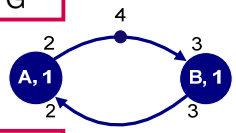
ACSD 2006

14 Traditional Throughput Analysis

- Convert the SDFG to a Homogeneous SDFG (HSDFG)
- Compute the throughput of the HSDFG

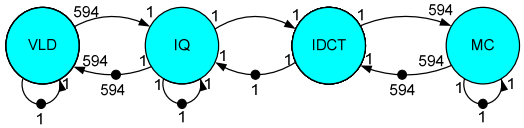
Disadvantage:
conversion may lead to an explosion in the size of the graph

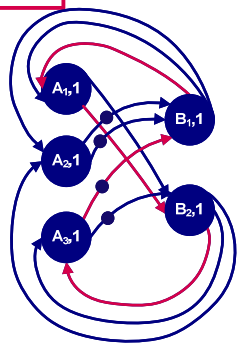
SDFG



HSDFG

Dataflow graph H.263 decoder





HSDFG with 1190 actors

15 Throughput Analysis: Our Result

All use conversion to HSDFG

	State Space	Dasdan Gupta	Howard	Young Tarjan Orlin
MP3 dec.	1. 10^{-3}	1. 10^{-3}	1. 10^{-3}	1. 10^{-3}
Modem	1.10^{-3}	82. 10^{-3}	81. 10^{-3}	81. 10^{-3}
Sample Rate	2. 10^{-3}	>1800	>1800	>1800
Satellite	56. 10^{-3}	>1800	>1800	>1800
H.263 decoder	10. 10^{-3}	>1800	>1800	>1800

Runtimes of various throughput analysis methods (in seconds)

16 Conclusions Throughput Analysis

- The first method to perform throughput analysis directly on SDFGs
- Experimental results show that the state-space technique outperforms all other existing techniques
- Can be easily integrated in simulation tools

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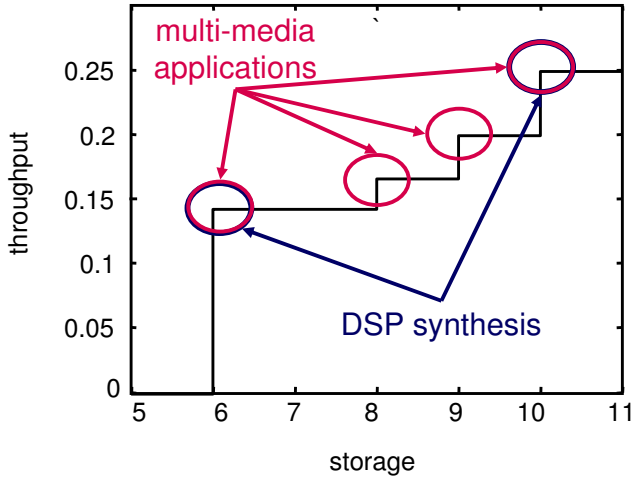
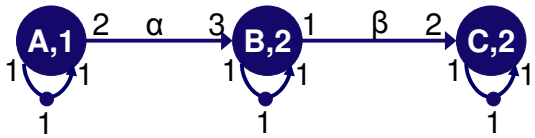
DAC 2006, IEEE T on Comp 2008

18 Trade-off: Storage vs. Throughput

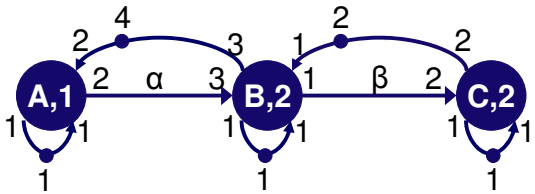


19 Storage Distribution



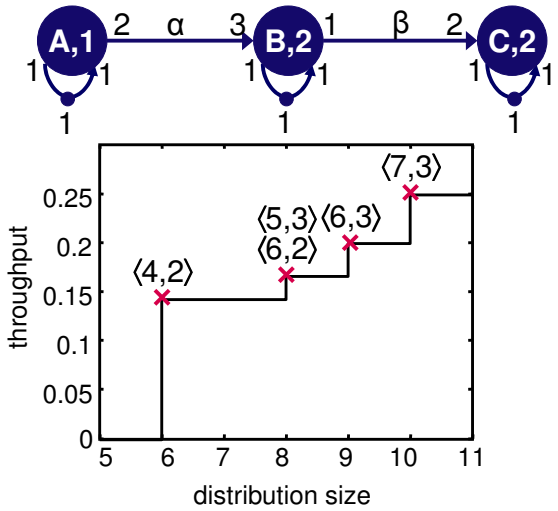
Tokens on channels must be stored in memory.

- Separate memory for each channel.
- Backward channels used to model storage space.



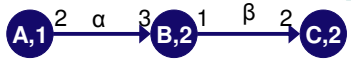
Storage distribution ⟨α, β⟩ → ⟨4,2⟩

20 Problem Definition



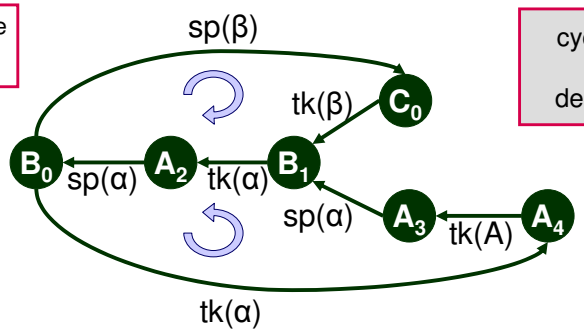
Find all minimal storage distributions for any possible throughput

21 Dependency Graph



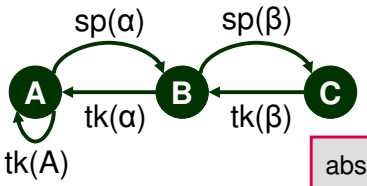
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A_0	A_1	B_0	B_0	A_2	B_1	B_1	C_0	C_0							
							A_3	A_4	B_2	B_2	A_5	B_3	B_3	C_1	C_1
														A_6	A_7

sp - space
tk - token

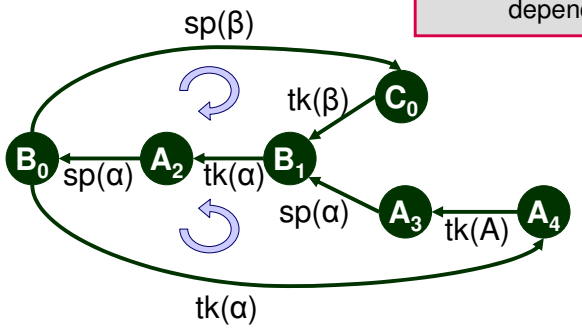


cycles denote storage dependencies

22 Abstract Dependency Graph



abstract dependency graph contains all storage dependencies



23 Design-Space Exploration Algorithm

Given an SDFG G with storage distribution δ
1. Compute throughput and abstract dependency graph Δ for G with δ
2. For each channel c with a storage dependency in Δ
3. Create new storage distribution by enlarging c
4. Repeat steps 1-2

All minimal storage distributions are found
when starting from storage distribution ⟨0,...,0⟩

24 Experimental Results

	Example	Satellite	MP3	H.263
#actors	3	22	13	4
#channels	2	26	12	3
min throughput > 0	1/7	0.18	1/137	1/21876
Distr. size	6	1542	12	4753
Max throughput				1/10000
Distr. size				8006
#Pareto points				3254
#Distributions	5	2	3	3254
Exec. time	1ms	7ms	2ms	53min

Approximation
increase buffers with n times the minimal step size

25 Conclusions Trade-off Analysis

- Exact minimum memory requirements for any possible throughput.
- Technique to search space of storage distributions efficiently.
- Experiments show feasibility of the approach.
- Technique can be combined with heuristics to prune the search space if necessary.

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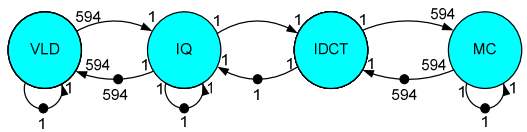
27 Parametric Throughput Analysis

H.263 decoder

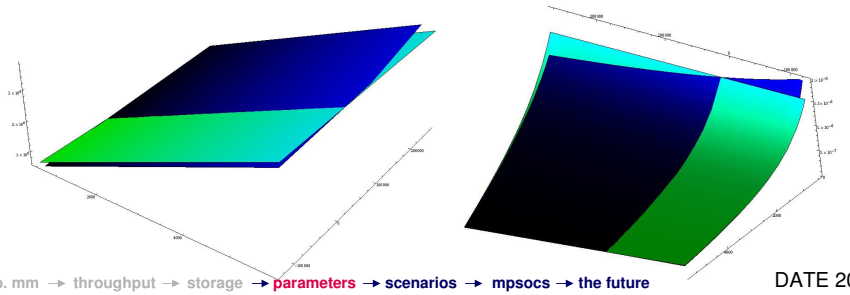
Parametric actor execution times



Divide and Conquer: divide space in throughput regions

throughput expression

$(\max \{593\ IQ + 594\ IDCT + MC,\ VLD + 594\ IQ + 593\ IDCT\})^{-1}$



DATE 2008

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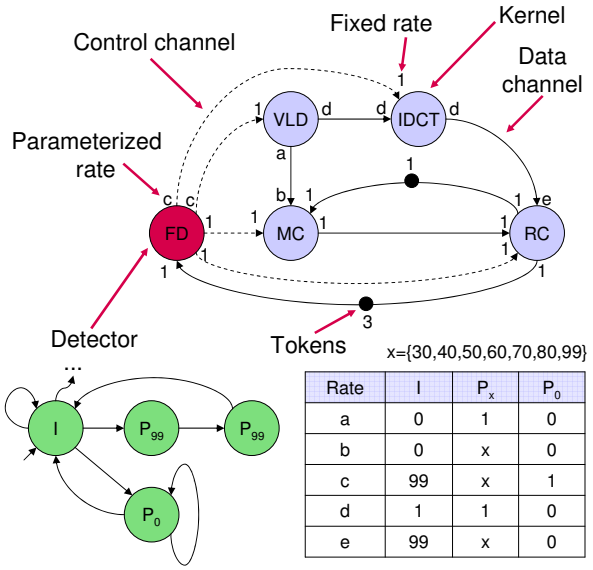
29 Scenario-aware H.263 Decoder Model

(FSM-based Scenario-Aware DataFlow (SADF))



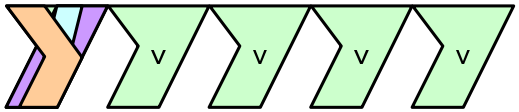
Rate	I	P_x	P_0
a	0	1	0
b	0	x	0
c	99	x	1
d	1	1	0
e	99	x	0

	Execution time	
VLD	P_0	0
	others	40
IDCT	P_0	0
	others	17
MC	I, P_0	0
	P_{30}	90
	P_{40}	145
	P_{50}	190
	P_{60}	235
	P_{70}	265
	P_{80}	310
	P_{99}	390
RC	I	350
	P_0	0
	P_{30}, P_{40}, P_{50}	250
	P_{60}	300
	P_{70}, P_{80}, P_{99}	320
FD	All	0

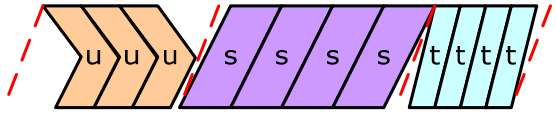
MEMOCODE 2006

30 Scenario-aware Performance Analysis

- SDF-based throughput analysis considers worst-case actor times



- Scenario-aware throughput analysis considers worst-case actor times per scenario, but it must consider scenario transitions



- Analyzing all scenario transitions separately can be avoided
- Separate scenario transitions with an invariant reference schedule
- For every scenario, our method allows to compute the bound on the completion time of an iteration

Marc Geilen

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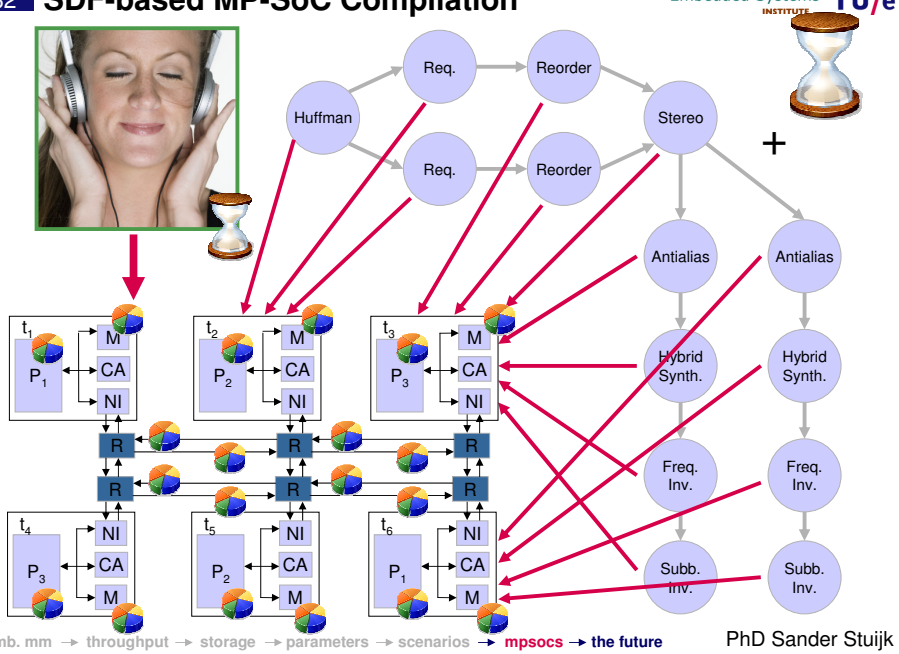
32 SDF-based MP-SoC Compilation



PhD Sander Stuijk

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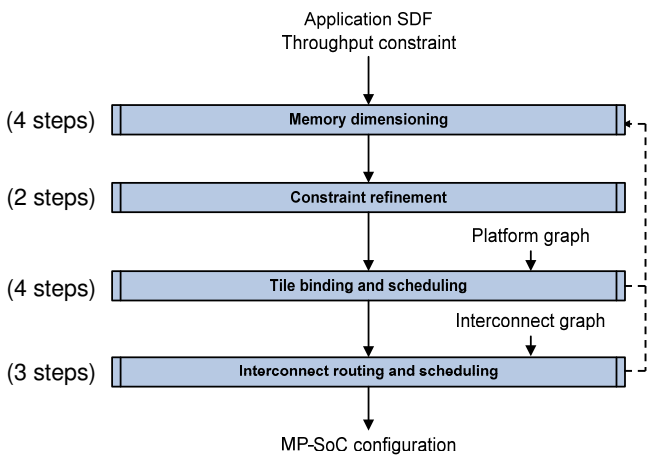

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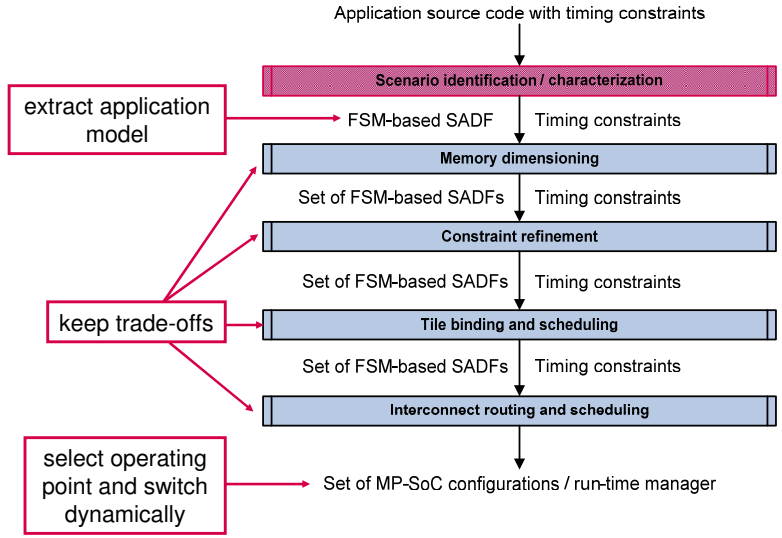
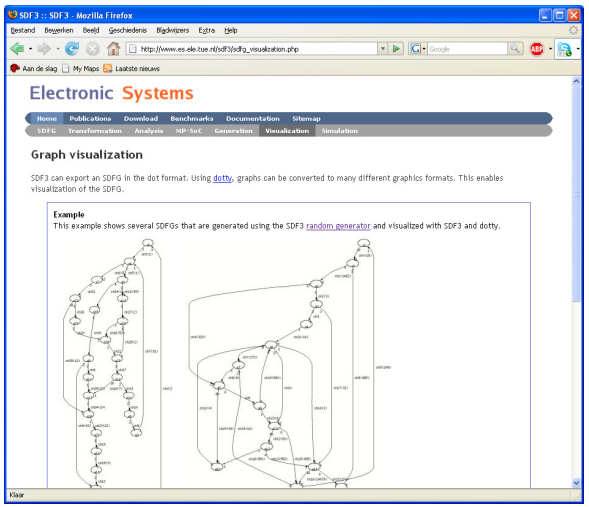
34 Horizon: Scenario-aware Flow



35 SDF3 Toolkit

www.es.ele.tue.nl/sdf3



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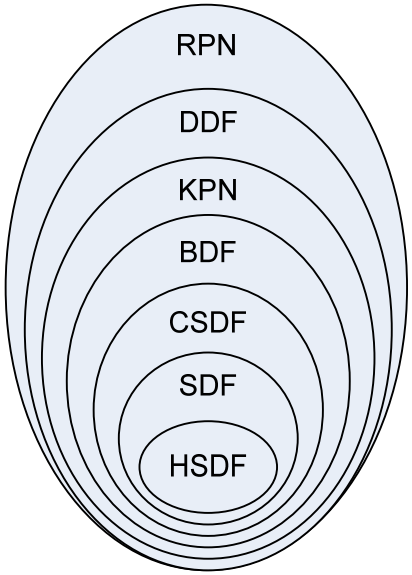
37 Dataflow MoCs Expressiveness Hierarchy



- BDF and larger: turing complete
- Better notions of expressiveness needed

RPN: Reactive Process Networks
KPN: Kahn Process Networks
DF: DataFlow
DDF: Dynamic DF
BDF: Boolean DF
CSDF: Cyclo-Static DF
SDF: Synchronous DF
HSDF: Homogeneous SDF

38 Challenges

- Suitable notions of expressivity
- Expressivity while maintaining analyzability and synthesizability
- Abstraction without loosing accuracy
- Composability and compositionality
- MoCs for non-functional aspects
- Unification of MoCs
- Multi-objective trade-off analysis
- Parametric analysis
- Model-driven design and synthesis flows
- Model-driven run-time systems

39 Thank you !

Questions ?

More info: www.es.ele.tue.nl/~tbasten/

'An understanding of the natural world and what's in it is a source of not only a great curiosity but great fulfillment.'
David Attenborough