Correlating System Test Fmax with Structural Test Fmax and Process Monitoring Measurements

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Outline

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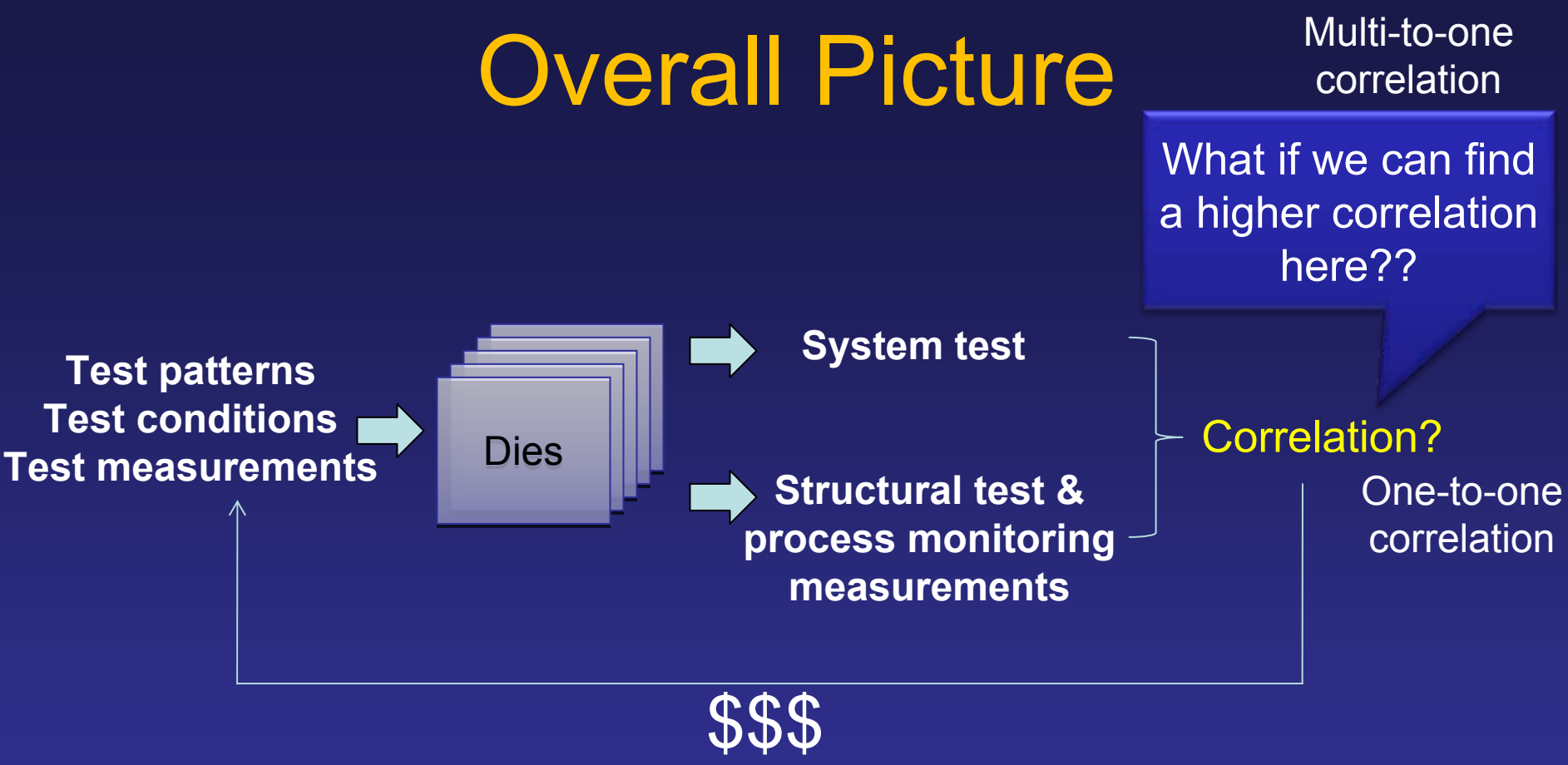
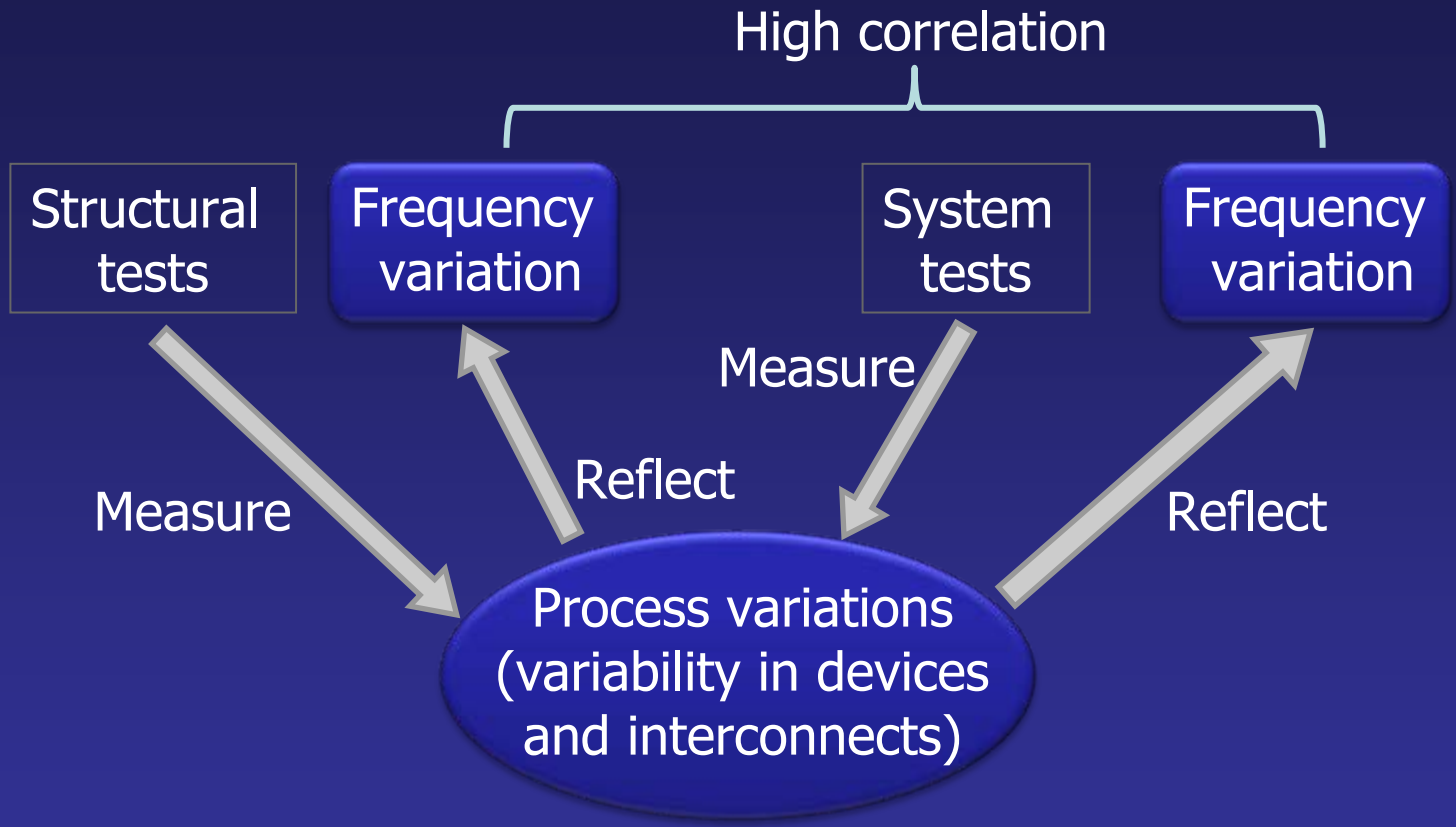
- 2. Correlation concept
- 3. Test measurement introduction
- 4. Methodology flow
- 5. Experimental results
- 6. Q&A

Overall Picture



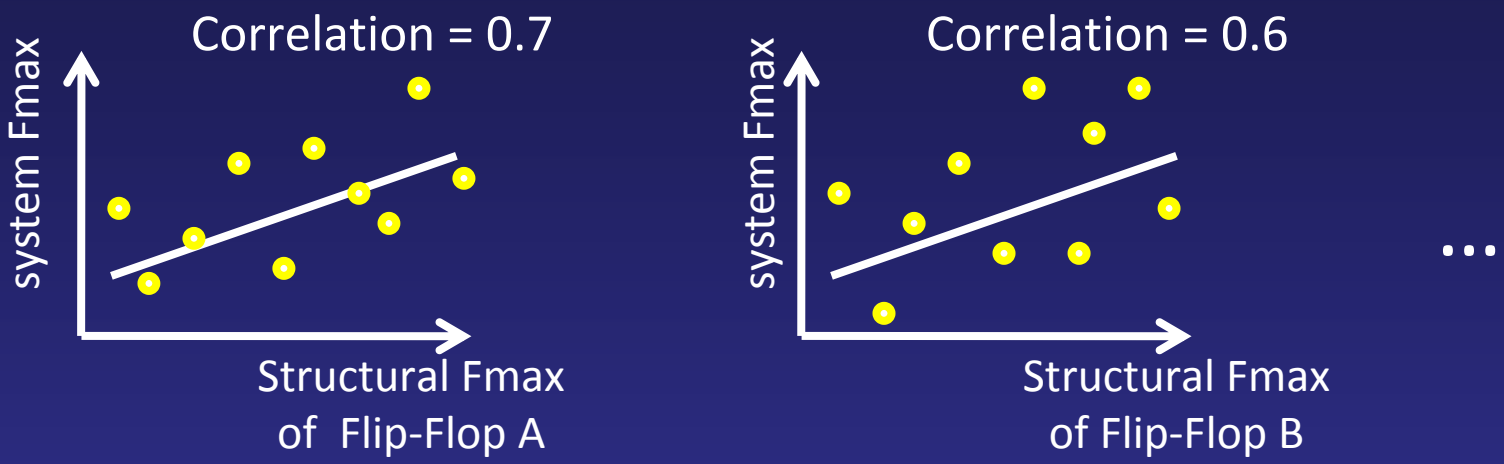
- We utilize a statistical data-learning approach to build a correlation engine, or a predictor, to obtain the predicted system Fmax based on information contained in alternative lower cost test measurements.
- The main idea is to use multi-to-one correlation method to replace simple one-to-one correlation method

Correlation Concept



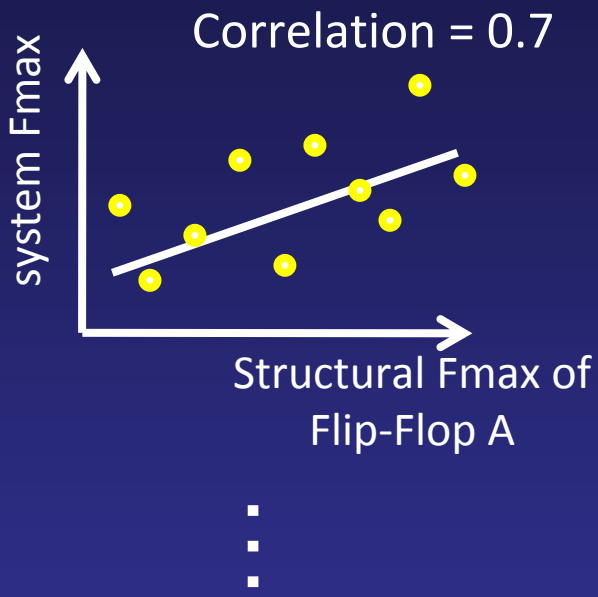
- The high correlation exist means both the frequency variations reflect the same underlying variability caused by some common source.

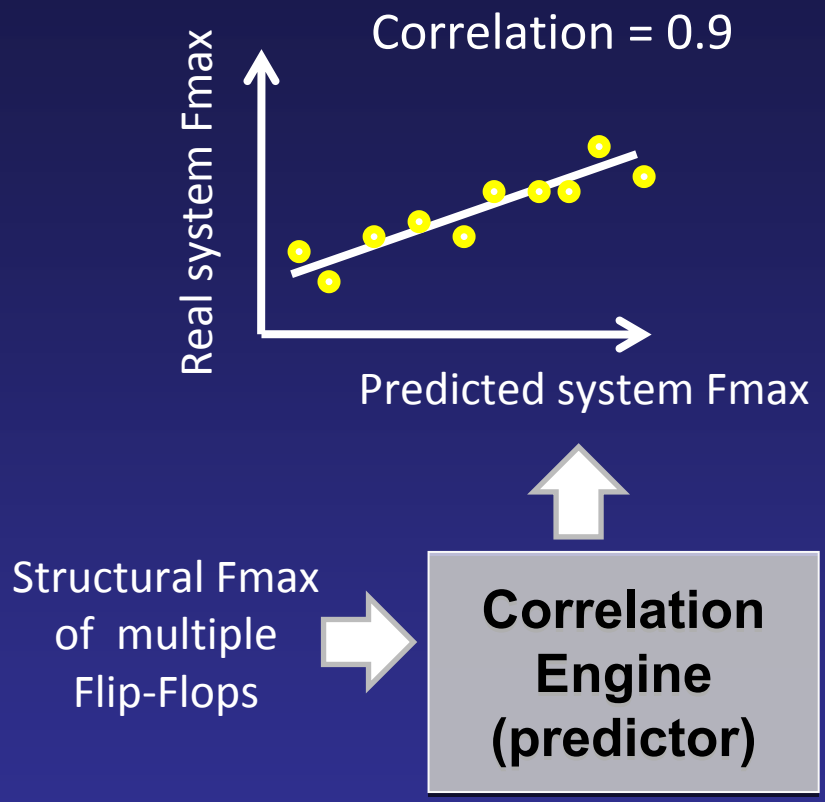
One-to-one Correlation Perspective



- Select the flip-flop with the highest correlation coefficient with system Fmax.
- If the correlation is low, alter test measurements or test conditions until a high correlation is achieved.

Multi-to-one Correlation Perspective

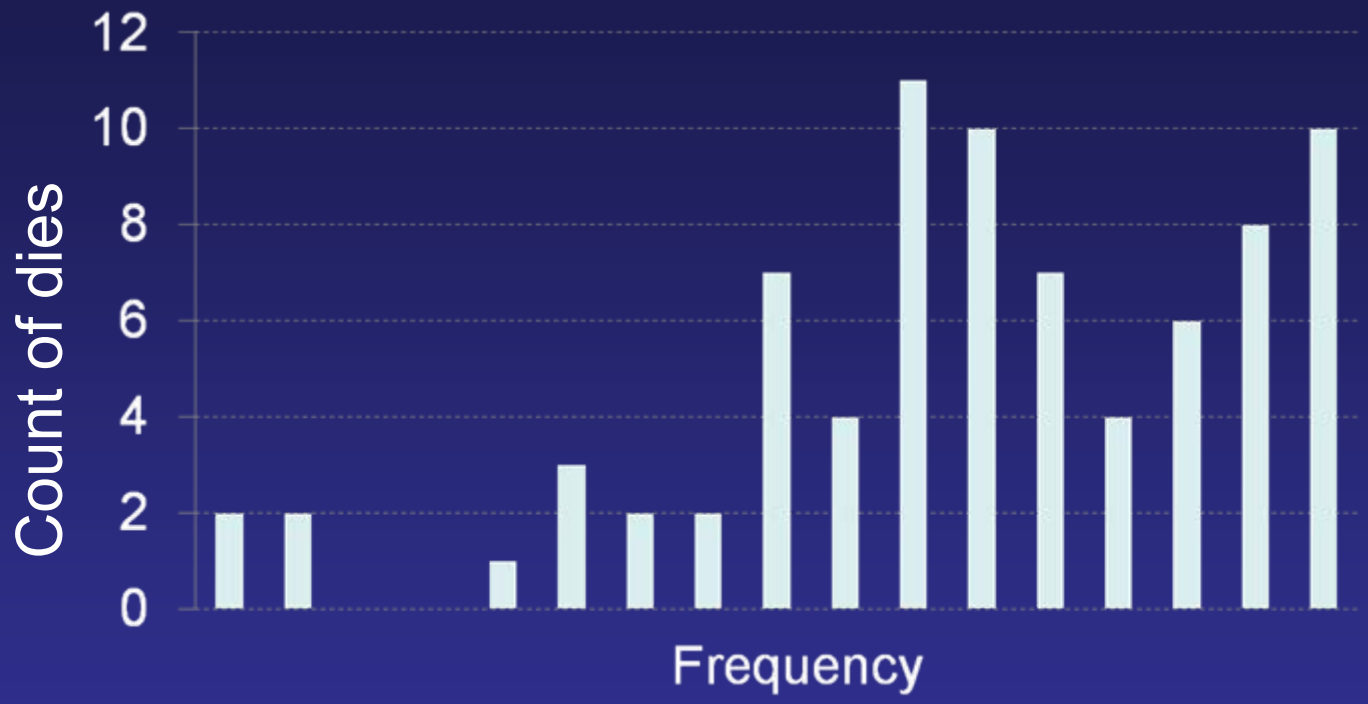




(a). One-to-one correlation perspective (b). Multi-to-one correlation perspective

- An alternative way to find out correlation in existing test data
- Instead of finding better correlation by altering test measurement and test condition, the proposed multi-to-one method finds higher correlation in existing data

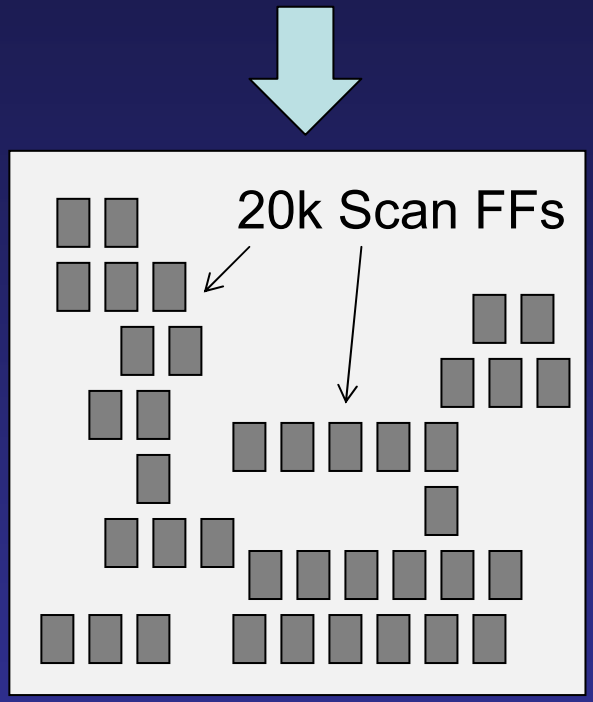
System Test Fmax (HST)



- System Fmax histogram for the 79 dies
  - System Fmax was measured successfully on these 79 dies.
  - Frequency variation can be observed here

At-speed structural test characterization

Using the transition delay fault pattern set



For frequency stepping from 1 ~ 5, first failing frequency reading for all 20k FFs

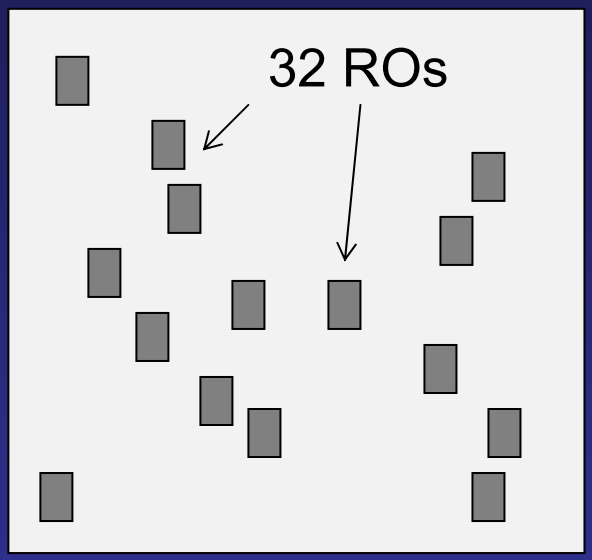
	FF1	FF2	FF3	FF4	FF5	…	FF20k
Die1	3.5	2.0	4.0	X	4.0		3.5
Die2	3.0	1.5	3.5	X	3.5		X
Die3	3.5	2.5	4.5	X	2.5		X
…							
Die79	3.0	1.5	3.5	X	3.5		X

Pick the FFs with readings across all 79 dies

Form a complete dataset. 1,507 FFs are selected because their first failing freq could be found through the freq stepping on all 79 dies

RO (Ring Oscillator) Test Characterization

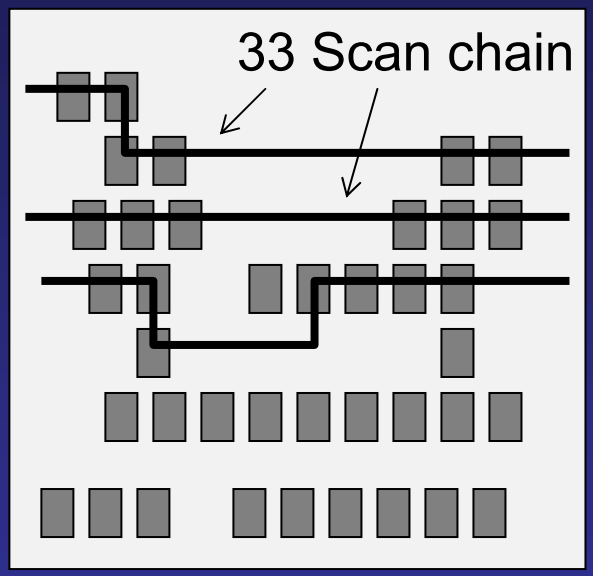
32 ROs are used to monitor process variation



Delay measurement for each RO

	RO1	RO2	RO3	…	RO32
Die1	1.5	2.0	2.5		1.5
Die2	2.0	2.5	3.5		3.0
Die3	2.0	3.0	2.0		4.0
…					
Die79	1.0	2.5	2.0		2.0

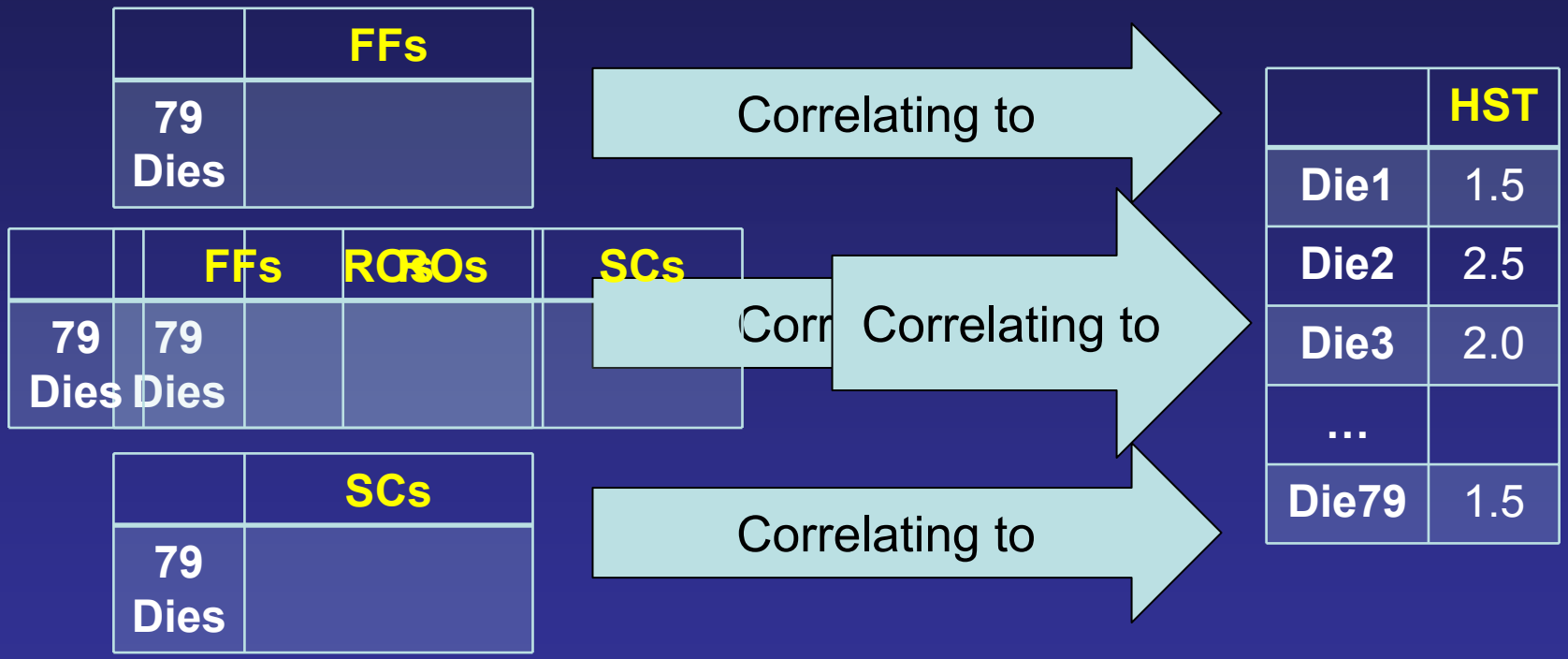
Scan Flush Test Characterization



Propagation delay measurement for each scan chain

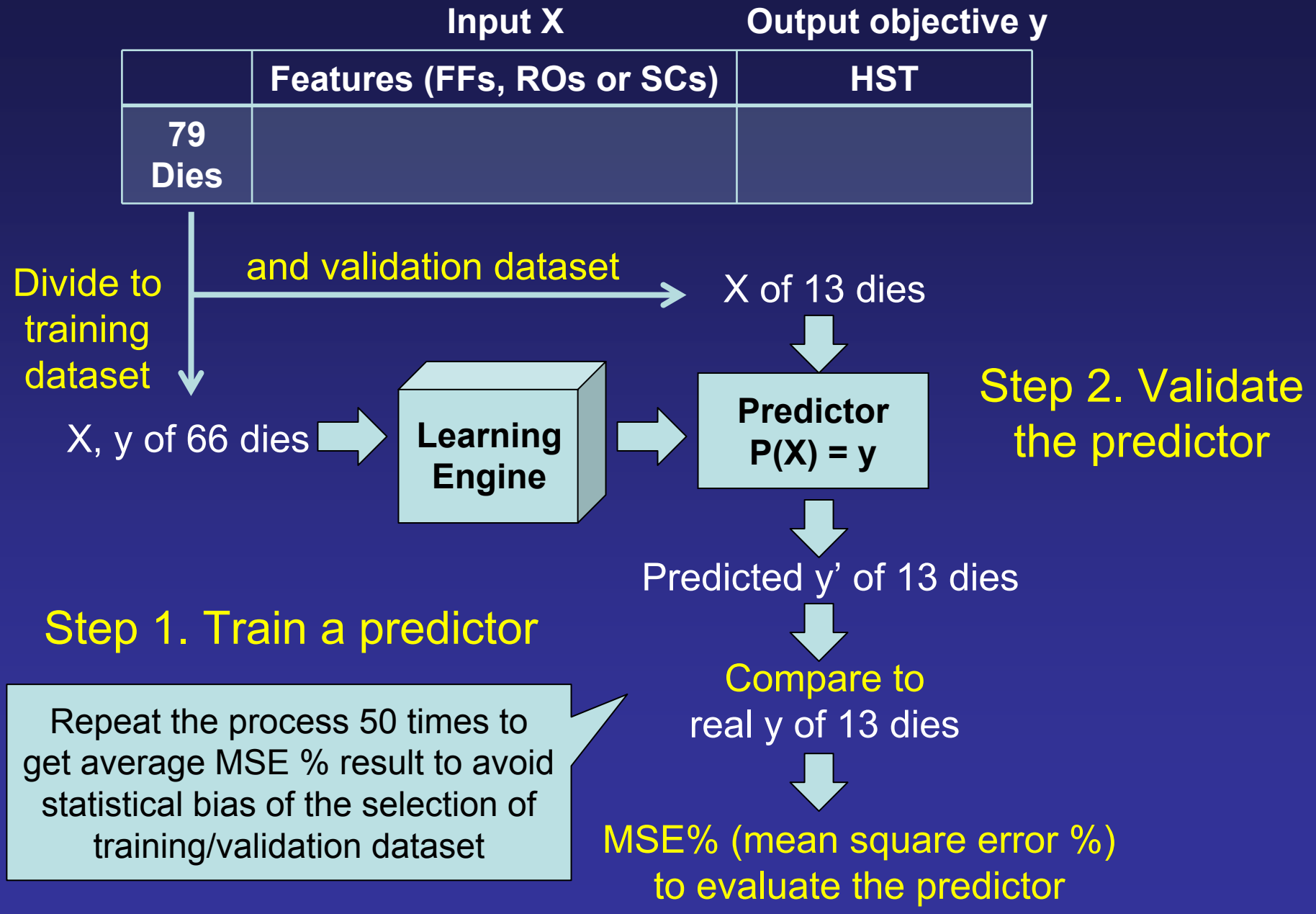
	SC1	SC2	SC3	…	SC33
Die1	3.5	3.0	4.5		2.5
Die2	4.0	2.5	4.5		2.0
Die3	2.5	1.0	3.0		1.0
…					
Die79	3.0	1.5	3.0		2.0

Correlating HST with 3 Different Test Dataset



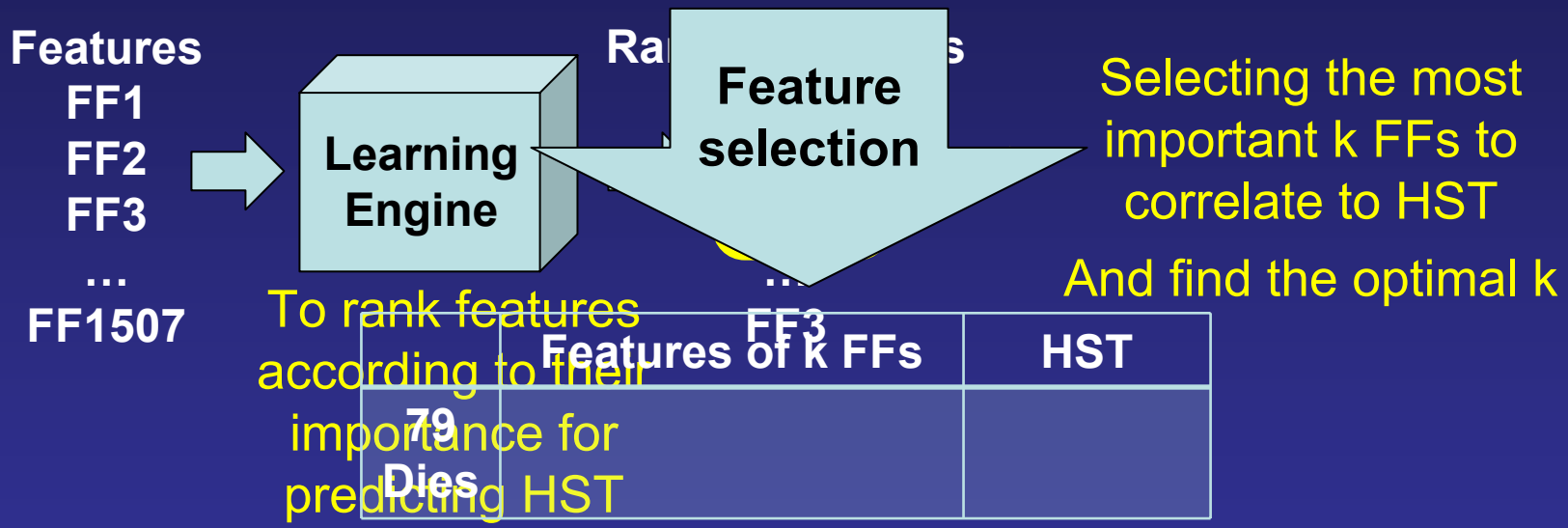
- With the multi-to-one correlation method, we can play with the dataset by using different combination of features

Methodology Flow



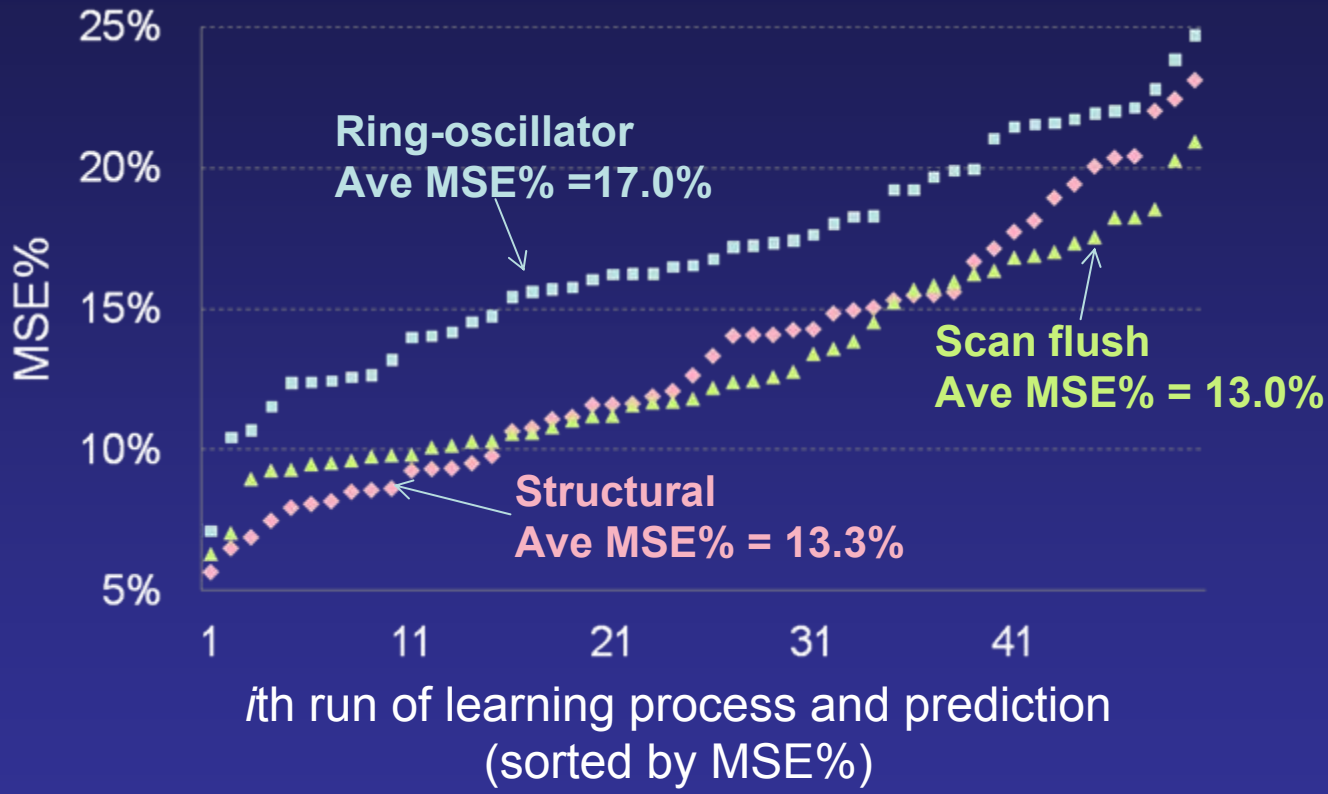
Feature Selection

	Features of 1507 FFs	HST
79 Dies		



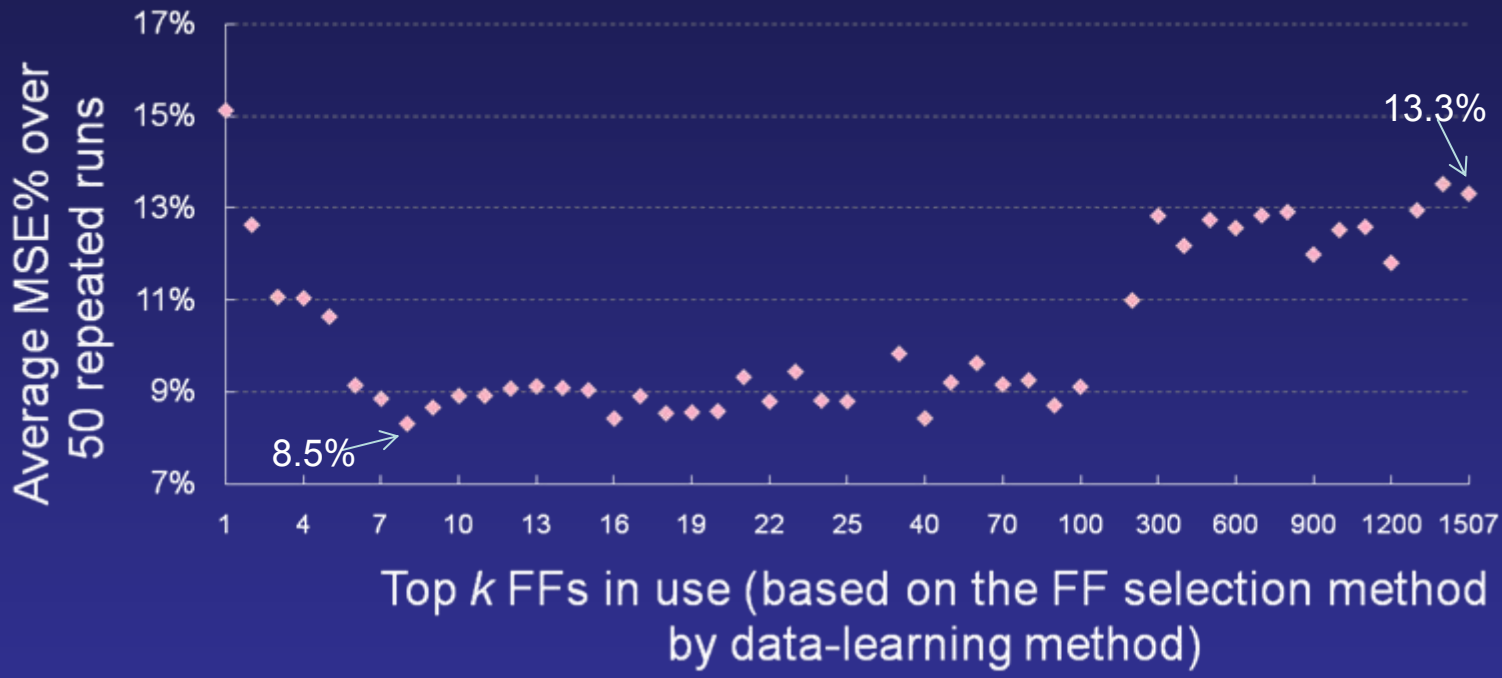
- To form a condense dataset
  - To guide the learning engine for better learning result
  - Too much features might cause overfitting problem
  - In production, using all 1507 FFs are too expensive

System Fmax Prediction Results (before feature selection)



- Scan flush test correlates better?
- In structural test, including all 1507 FFs might degrade the learning process

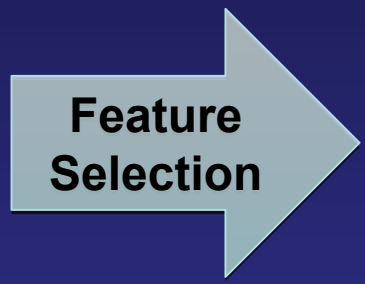
Feature Ranking Result



- Selecting a subset of 8 FFs gives us the best correlation results
- Let's use these 8 FFs instead of all 1507 FFs

Before and After Feature Selection

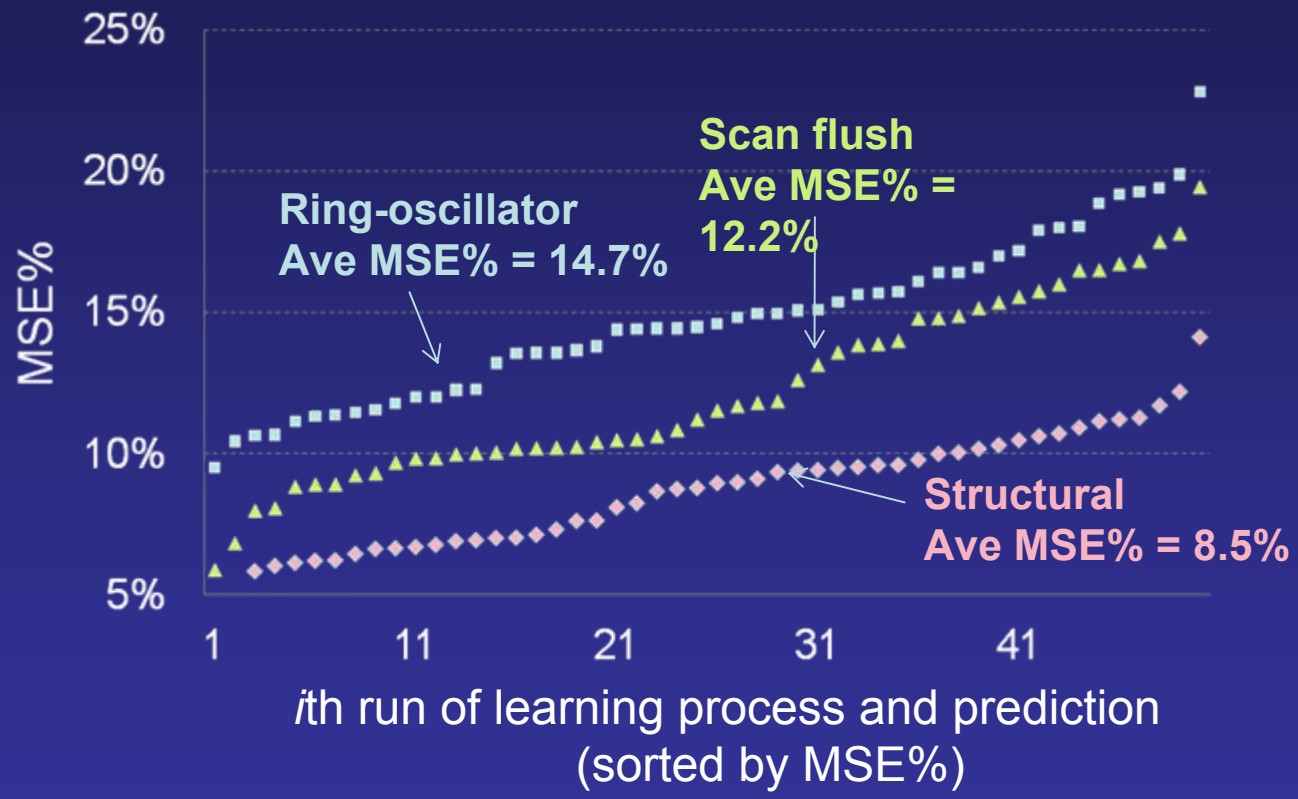
	Feature count	MSE% with all features
Structural	1507	13.3%
Ring oscillator	32	17.0%
Scan flush	33	13.0%



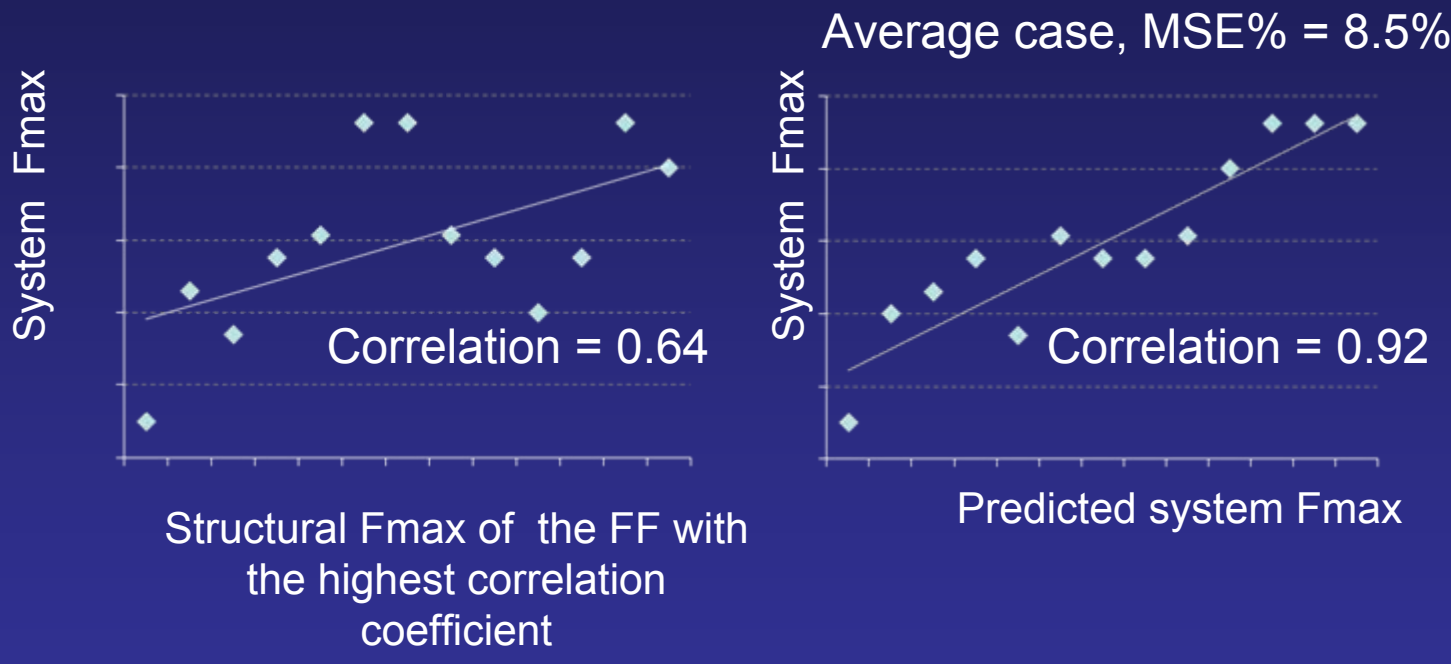
Selected feature count	MSE% with selected features
8	8.5%
5	14.7%
4	12.2%

- Structural test improves the most.
- Structural test correlates the best.
  - Which makes more sense

System Fmax Prediction Result After Feature Selection



Comparison of Simple Correlation and Data-learning Correlation Result



- Multi-to-one correlation is better

Thank you!
Q&A