

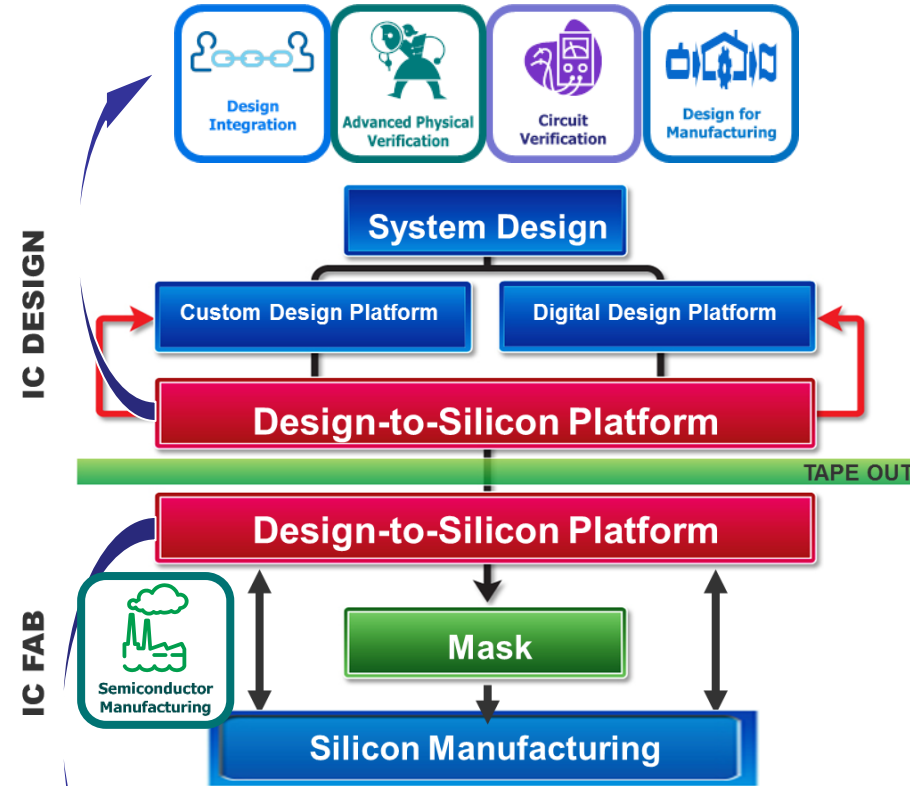
# Calibre PTO flow

Martin Niehoff

Application Engineer – Calibre Manufacturing Solutions

January 24<sup>th</sup>, 2019

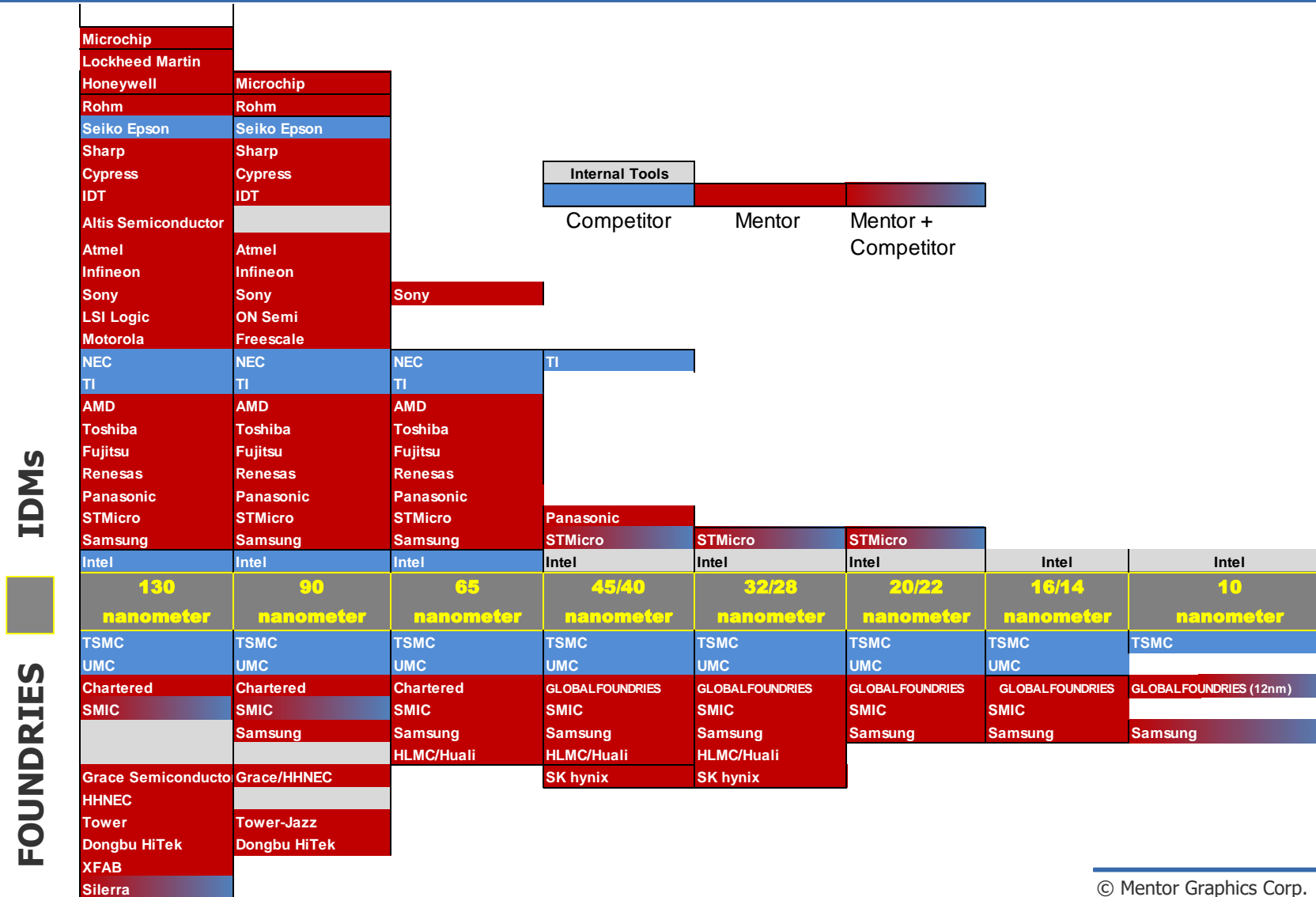
# Calibre is the Market Leader for Entire Post Tape Out Flow



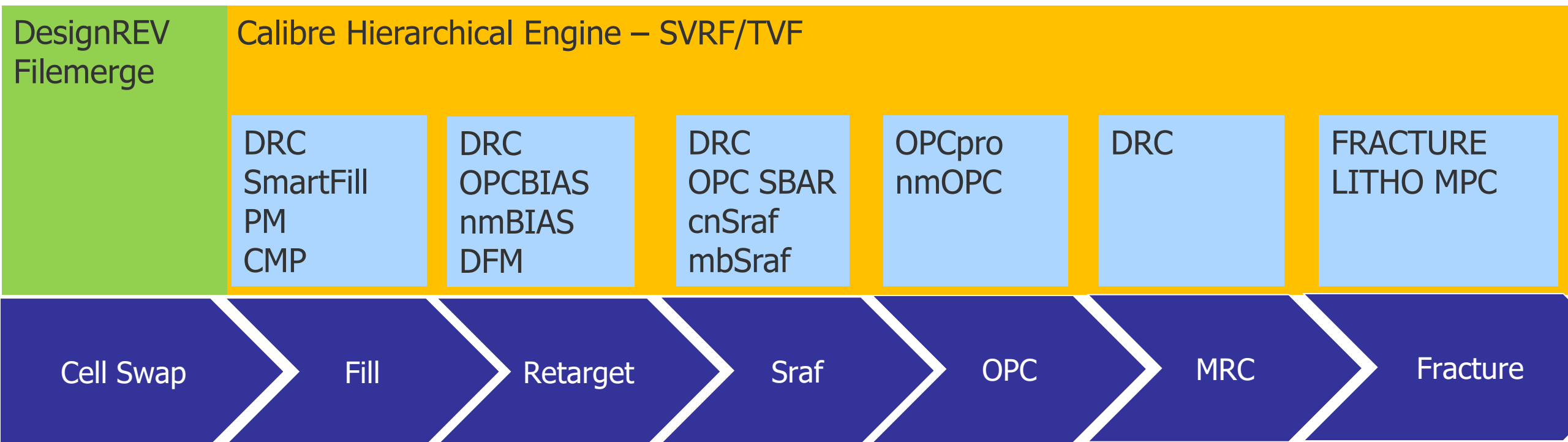
- Calibre is the Market Leader in DRC & DFM [ $> 60\%$  MS]
- All logic foundries use Calibre in the MDP flow for Logic Operations & MRC checks
- Calibre OPC and MDP solution Deployed at 38 fabs



# Calibre Production OPC (SRAF, OPC, OPCV) Flow Spans Multiple Process Nodes



# Calibre PTO flow / tool mapping



# DESIGNREV

Cell Swap

Fill

Retarget

Sraf

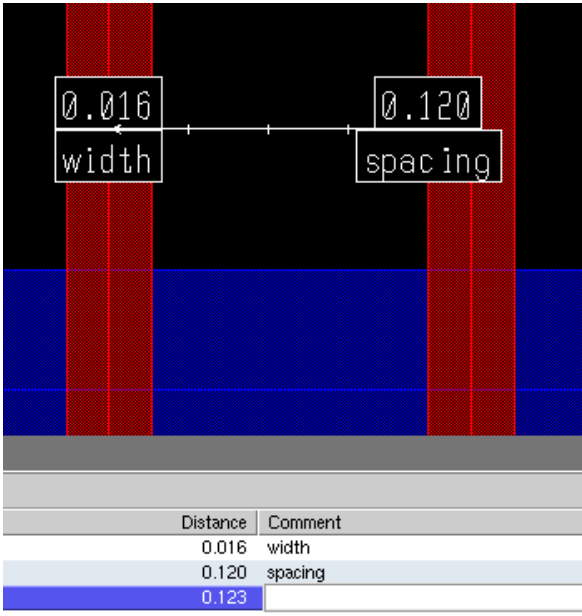
OPC

MRC

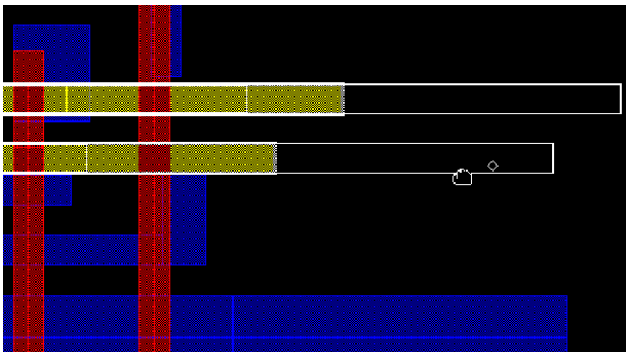
Fracture

# Calibre DESIGNrev Fast GDSII & OASIS Viewer and Editor

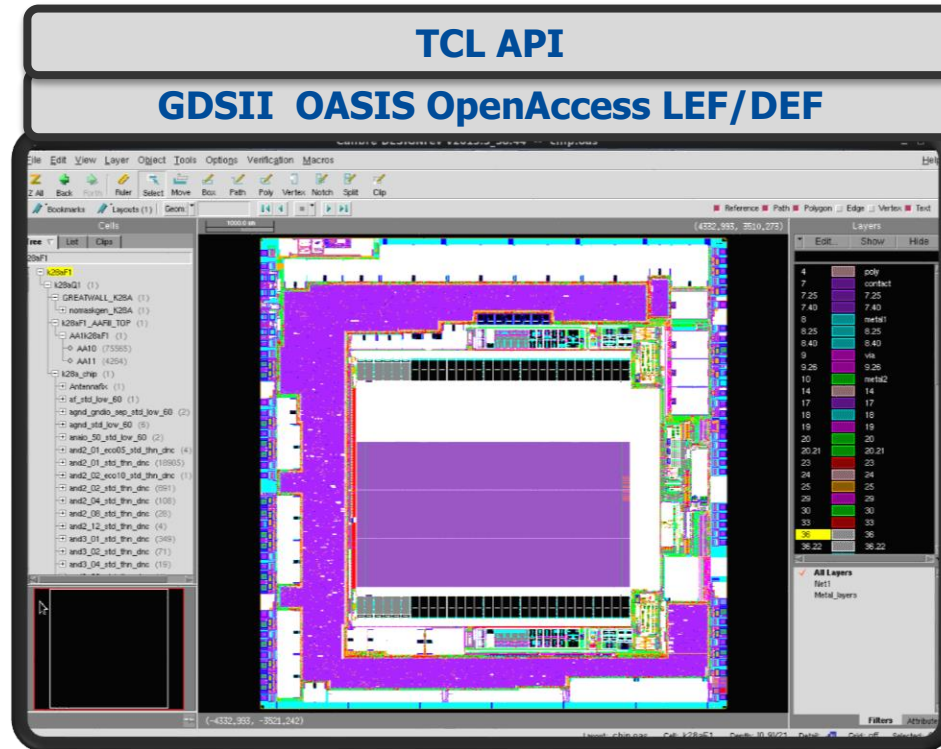
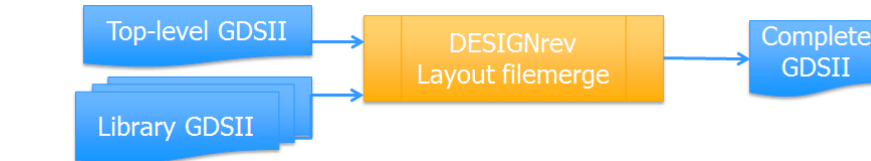
## Measurements



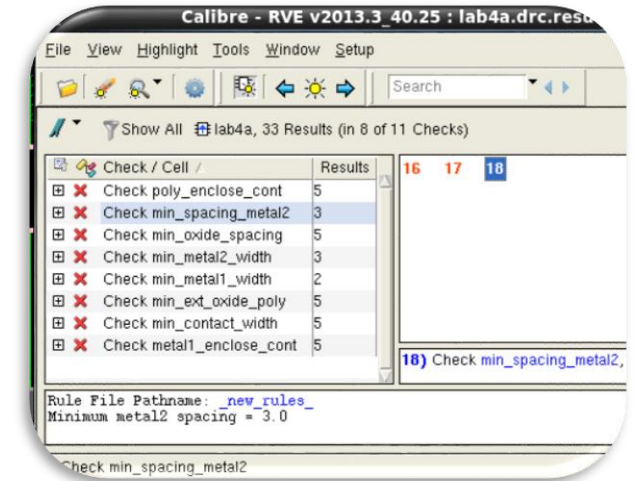
## Editing



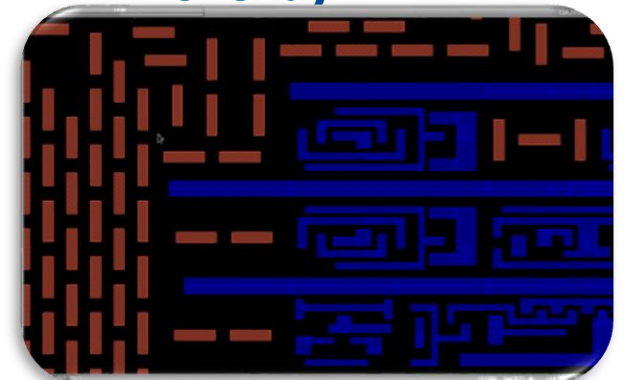
## Chip Assembly



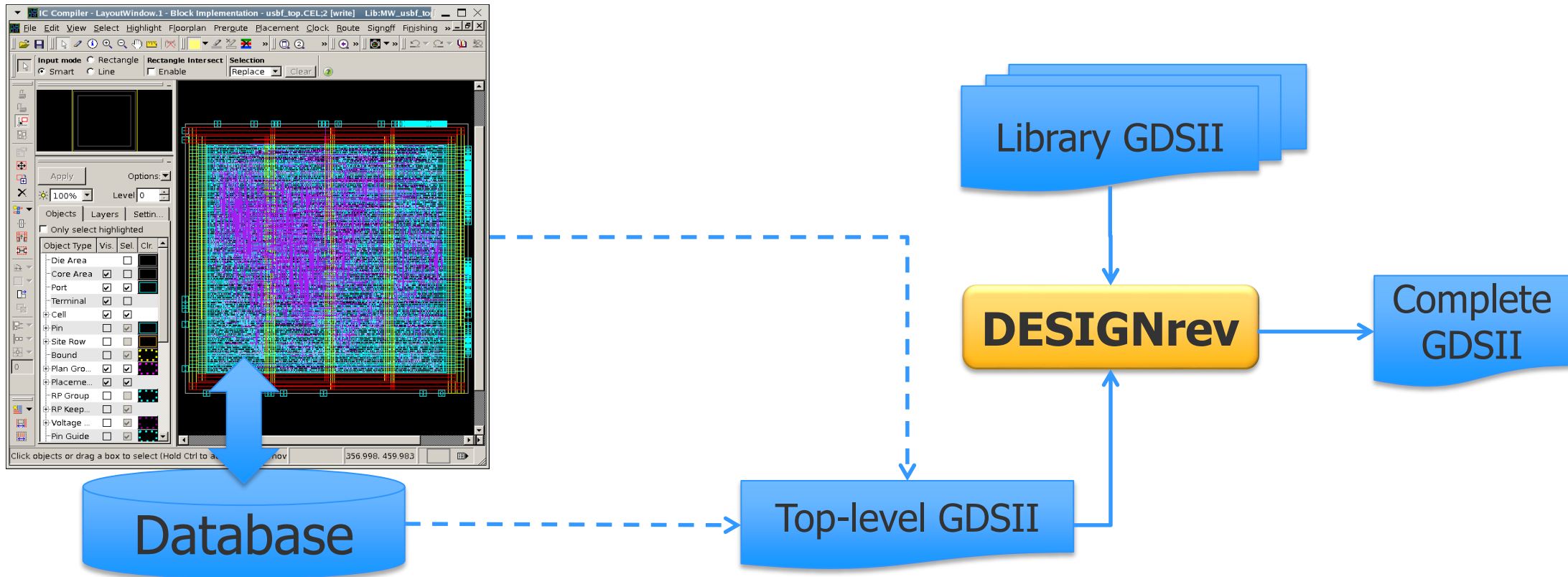
## Full-chip debug



## In tool XOR & Overlay



# Reduce Time with DESIGNrev Filemerge



- Direct read decouples the stream-out from the design tool
- DESIGNrev filemerge is superior in speed and flexibility
  - Specific functionality for library conflicts

# Customer Success Story

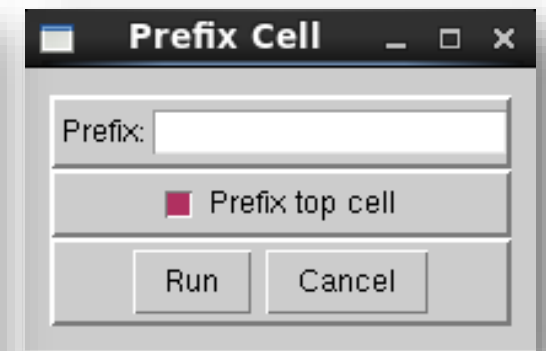
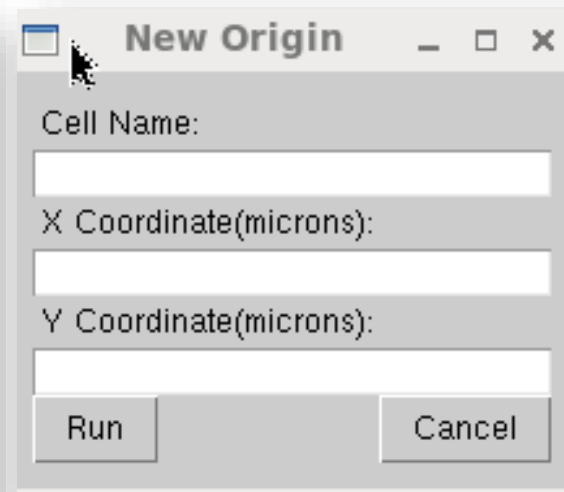
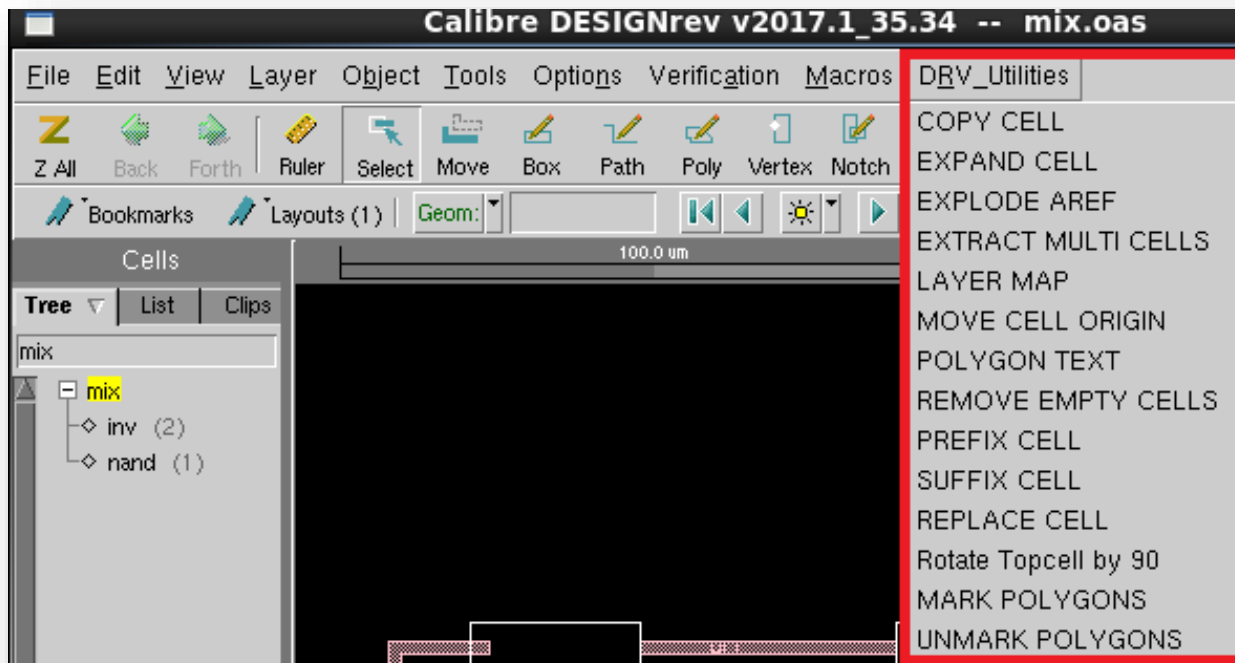
- Problem: Use P&R or layout editor take HOURS to merge
  - Analog design in layout editors ( Virtuoso , Laker)
  - Toplevel routing in P&R tool (ICC, EDI )
  - Resulting in hundreds of libraries with a couple GB in size
  
- DESIGNrev's filemerge flow: turn hours into minutes

Merged Database Size	Technology Node	Virtuoso Merge	DESIGNrev layout filemerge	Savings
552 MB in GDS format	7 nm	25 min	1 min	<b>96 %</b>
25 GB in GDS format	28 NM	20 hours	15 min	<b>98%</b> <b>19.5 hours</b>



# Configurable GUI with Custom Functionalities

- Supports the open standard TCL/TK macro language for extensive tool customization
- User-built menu items to provide easy access to custom functionality such as scripts



# FILL SOLUTIONS

Cell Swap

Fill

Retarget

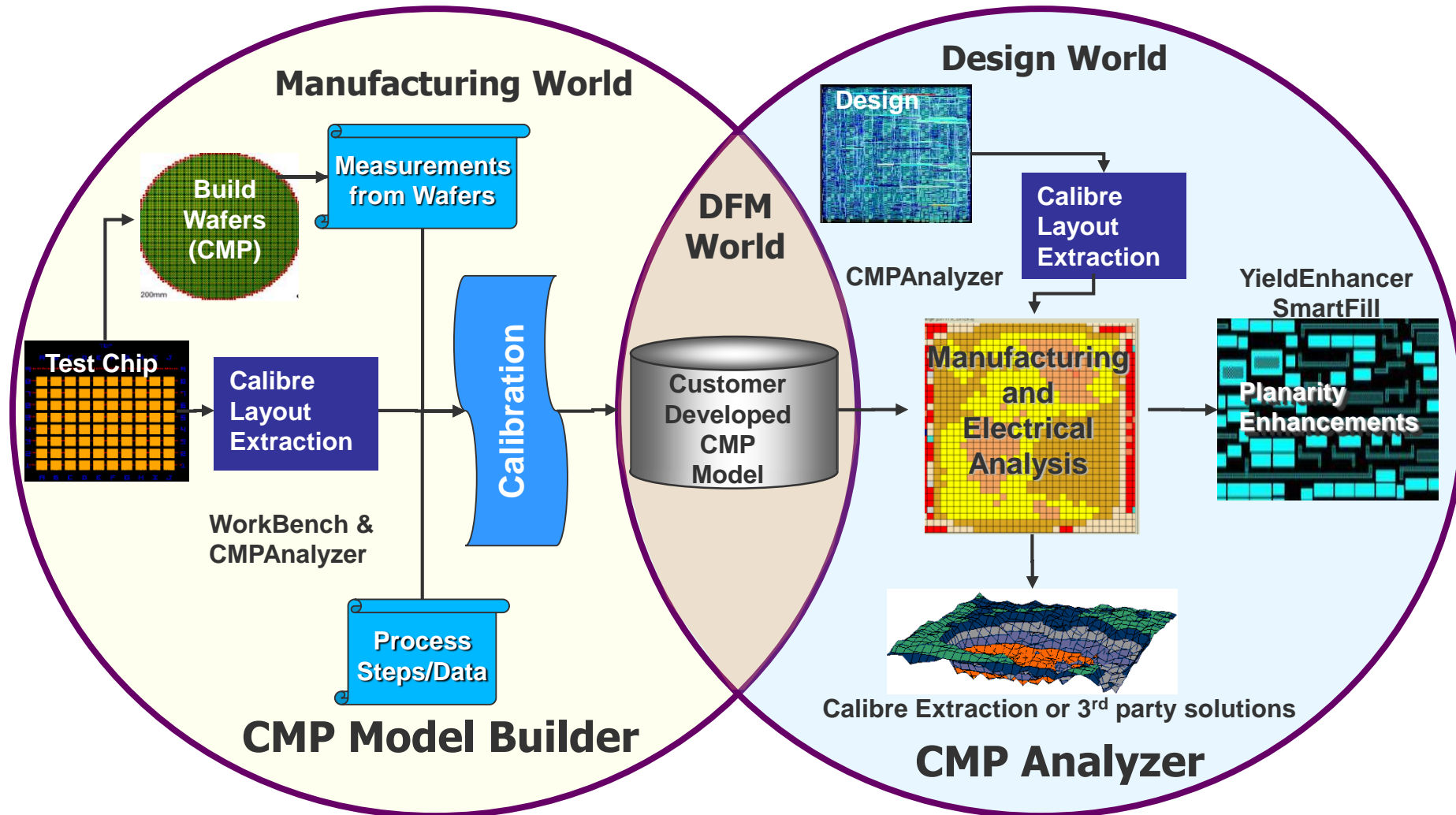
Sraf

OPC

MRC

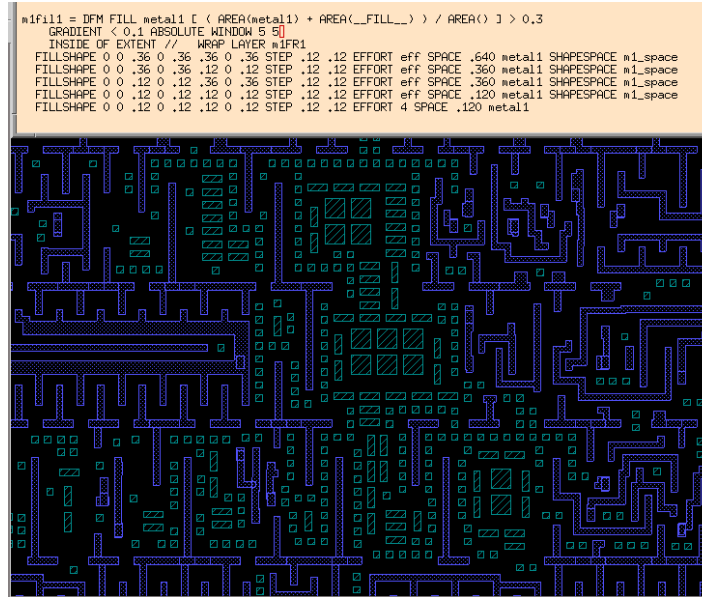
Fracture

# CMP Virtual Manufacturing World



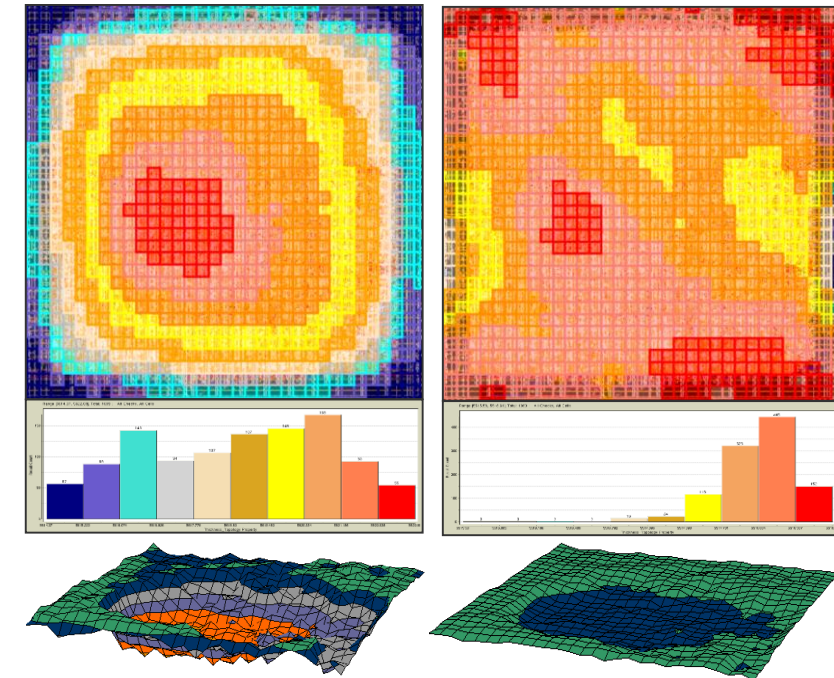
# Calibre SmartFill

- Achieves density requirements

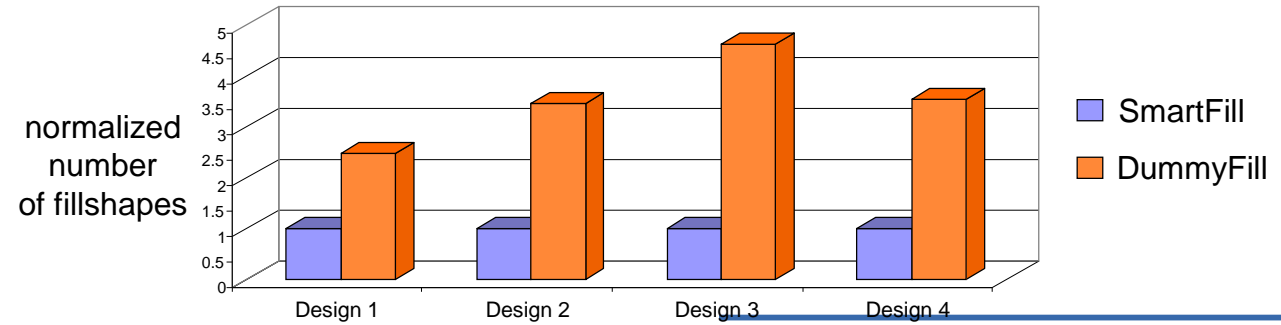


Pre-Fill

Post-Fill

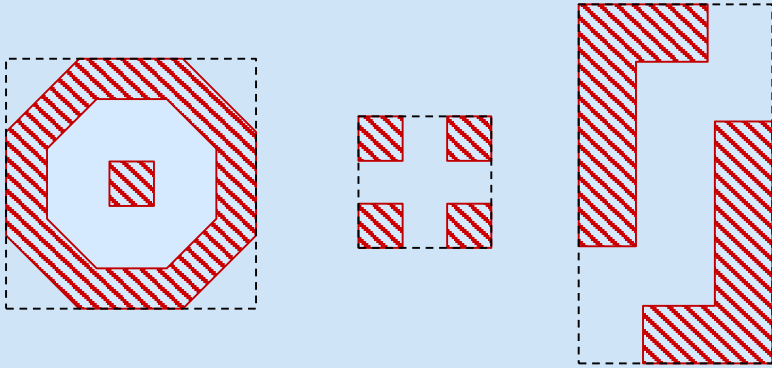


- With less fillshapes

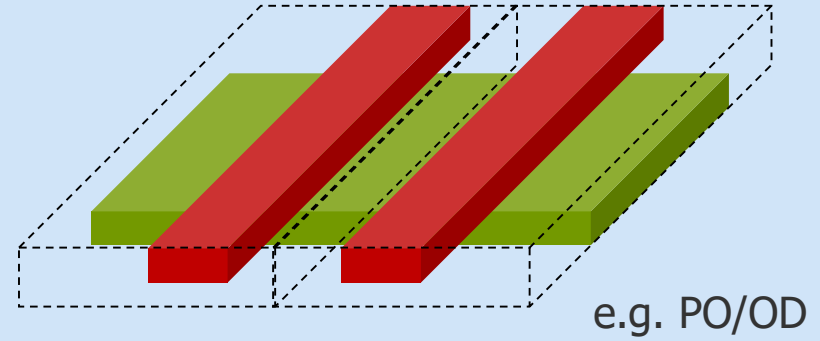


# Supported patterns

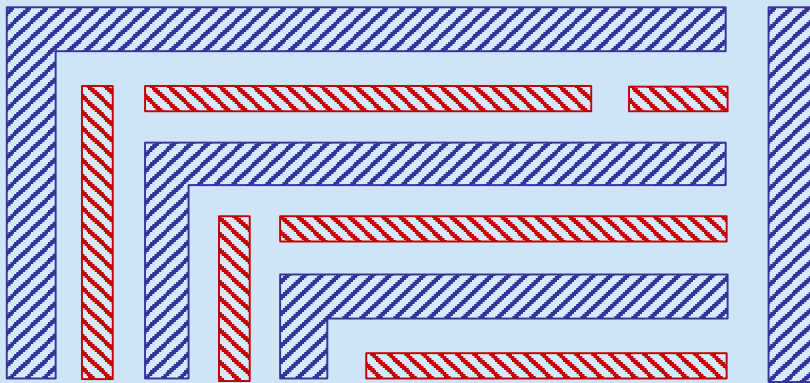
## Multi-shape fills



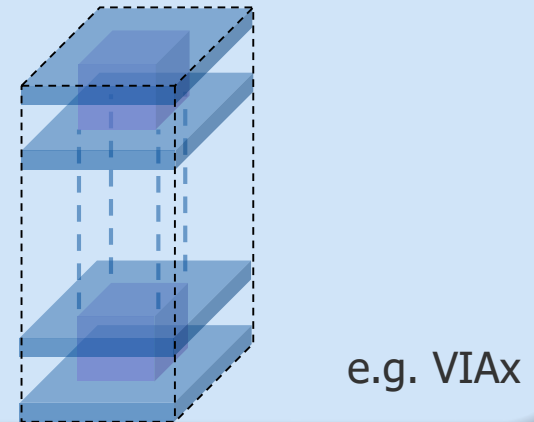
## 3D fills



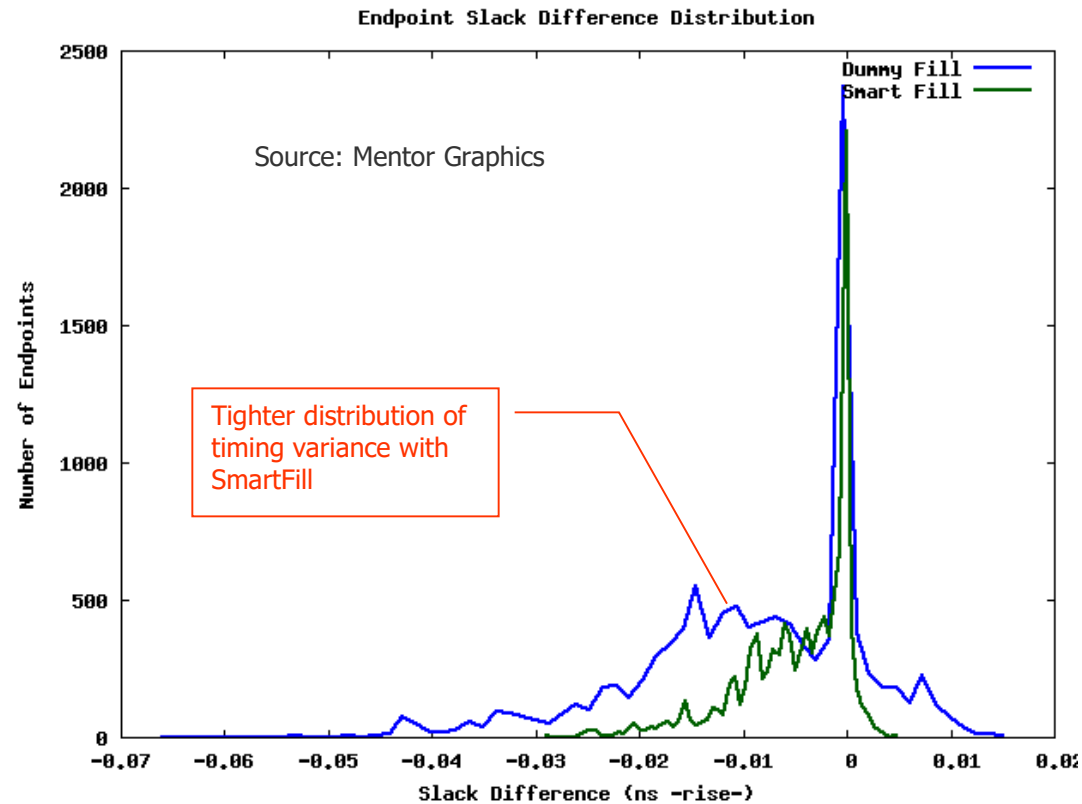
## Autorotate stretch fills



## Flexible stack fills



# SmartFill reduces the timing impact



**Much less timing impact versus DummyFill in average, reduced variance, zero/minimum impact on critical nets**

# RETARGETING

Cell Swap

Fill

Retarget

Sraf

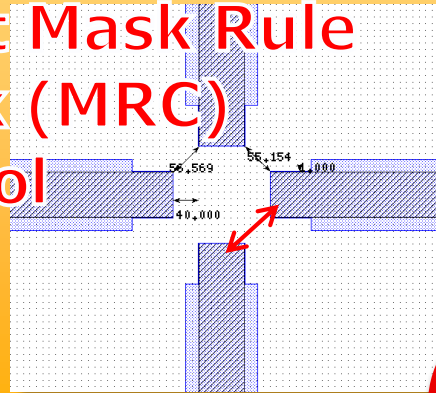
OPC

MRC

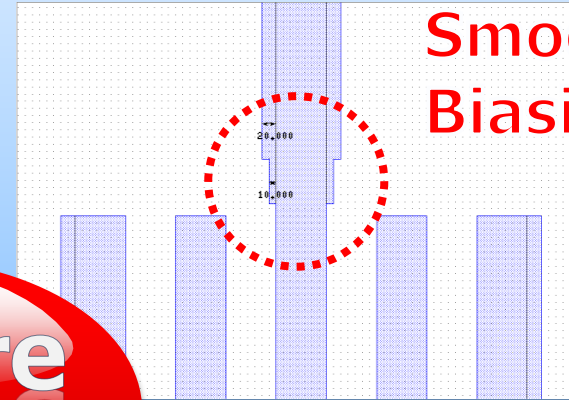
Fracture

# Accurate, Efficient and Easy to Use Biasing Engine

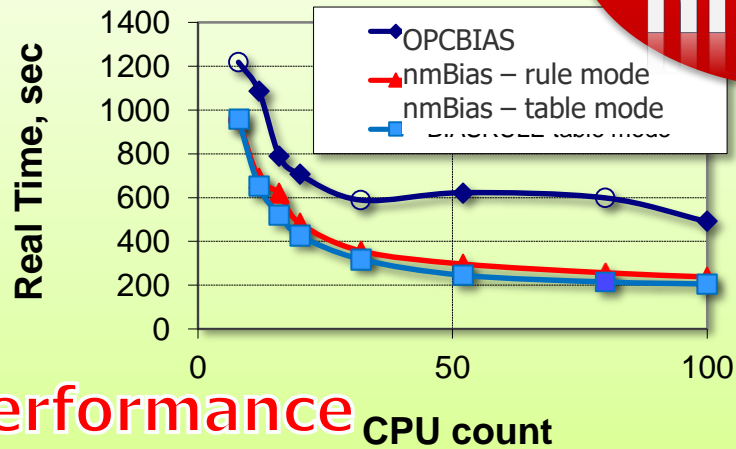
Smart Mask Rule  
Check (MRC)  
Control



Smoothed  
Biasing



Calibre  
nmBias



Performance CPU count

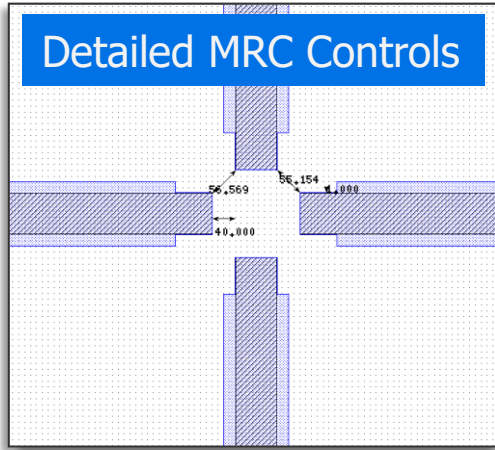
- Rule table interpolation
- Table format scripting
- Biasing until reaching minimum space or width constraints
- Tag-based biasing and controls

Ease-of-Use

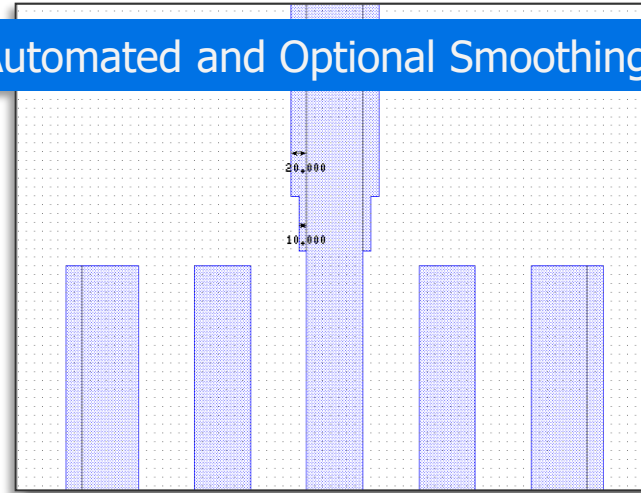


# Retargeting with nmBias

Detailed MRC Controls

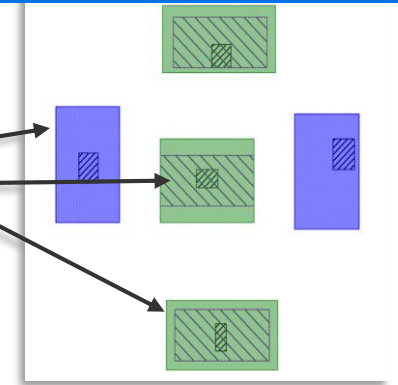


Automated and Optional Smoothing

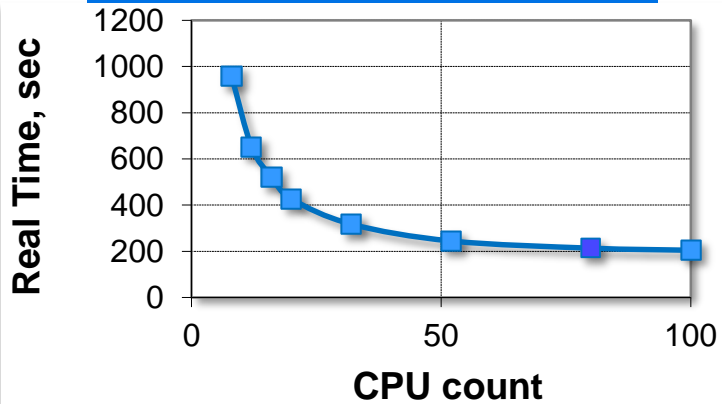


Up-size Via to meet Min-Area spec.

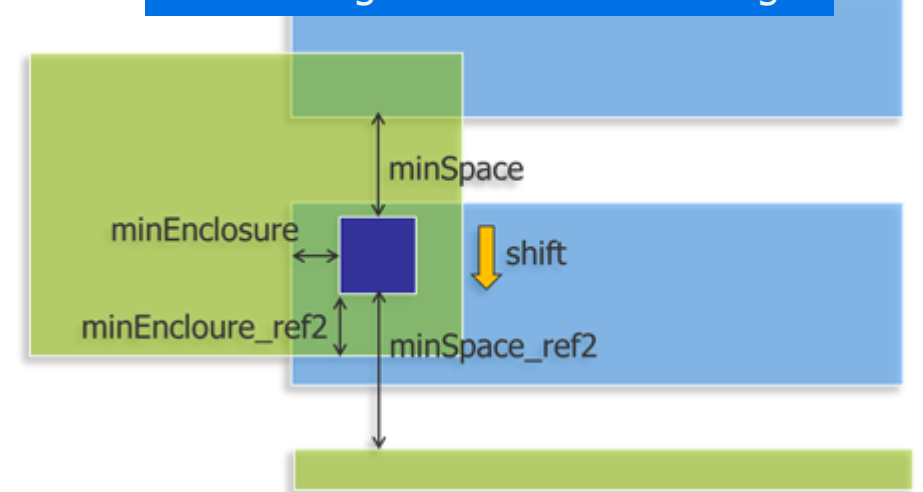
Dummy via  
Marker  
Final output



Fast Distributed Processing



Via Shifting to Maximize Coverage



# Pattern Matching For Retargeting

## ■ Retargeting Definitions

- Via doubling → considered part of fill flows
- Edge movement for Pre-OPC
  - Most customers use DRC/YE/PM property approach
  - In addition to PM, nmBIAS or both

	Foundry1	Foundry2	Foundry3	Foundry4
Tools	DRC/YE/PM/nmBIAS	DRC/YE/PM/nmBIAS	DRC/YE/PM/nmBIAS	DRC/YE/PM
Overview	Property based calculation and PM to do edge movement	driven by hotspot locations, explore solutions & replacements	computational approach that weighs the patterns & corresponding fixes	Property based calculation and edge movement

- OPC retargeting for lithography process → correcting and imaging

## ■ Natural evolution → Foundry4 to use PM in retargeting:

- PM can be used to catch corner cases –simplify the DRC SVRF-
- Detect problematic patterns (learning process; previous designs, LSG, PVG ... etc)

# SRAF SOLUTIONS

Cell Swap

Fill

Retarget

Sraf

OPC

MRC

Fracture

# Overview Calibre SRAF Tools

## Calibre nmSRAF License

### OPCsbar

- First Generation Tool
- Rule-Based SRAF Insertion

### cnSRAF

- Released in 2010.1
- Template-Based SRAF Insertion

### mbSRAF

- Released in 2011.3
- Model-Based SRAF Insertion

## Calibre nmSRAF

OPCsbar target edge classification placement

cnSRAF edge\_template-based placement

- placement can manually be Inverse Lithography tool (ILT) based
- best flexibility for capturing shape requirements

mbSRAF process model "gradient" placement

**Calibre nmSRAF license can invoke all three SRAF tools.**

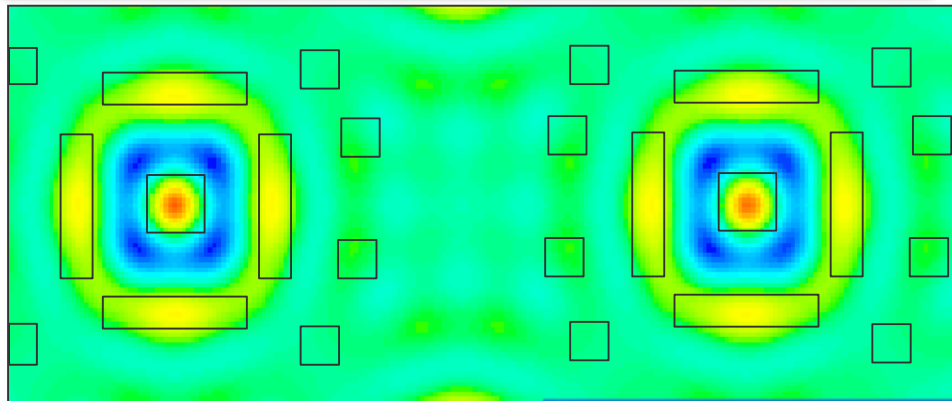
# Model and Rules Based SRAF Solutions

## Modelbased SRAFs

SRAFs placed automatically by model-driven objective function.

Advantages: Simple recipe setup, maximum SRAF coverage of complex 2D geometries. Only ~25% slower than Rulesbased.

Application: Any complex 2D Logic Layouts (Cont/Via/Metals).

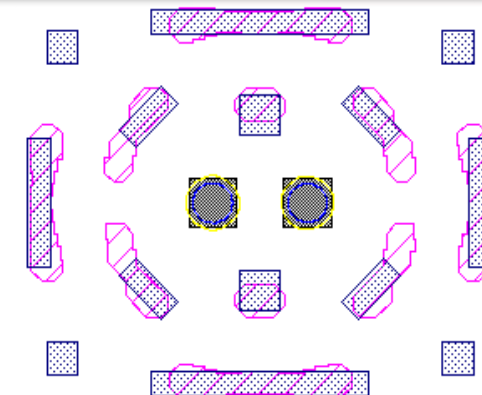


## Rulesbased SRAFs

SRAF placement is tuned to ILT mask shapes.

Advantages: Perfectly consistent and deterministic placement.

Application: Ideal for memory arrays, or any situation where perfect consistency is required.

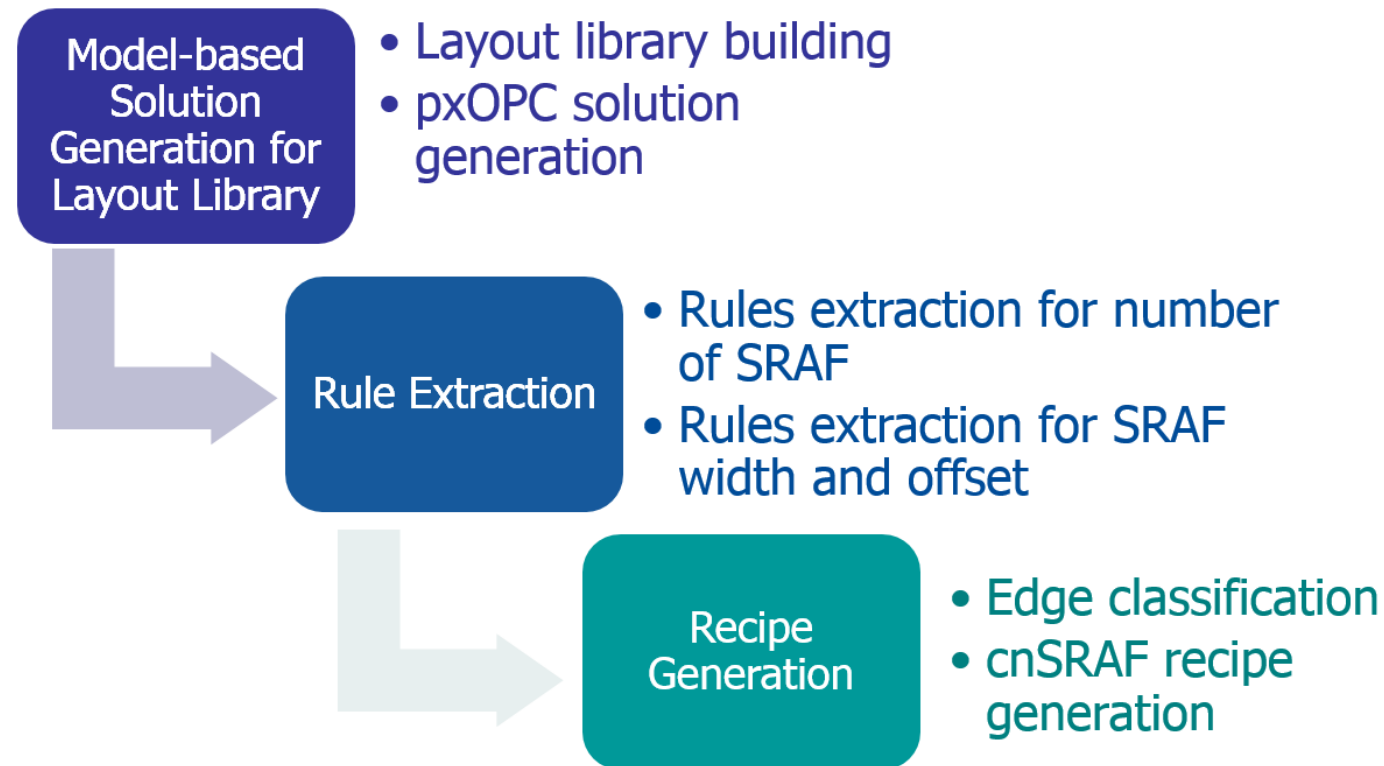


**Pink-** ILT;  
**Blue-**nmSRAF

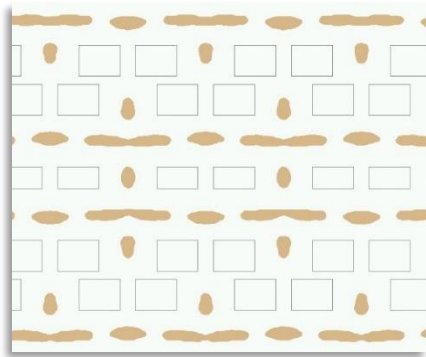
Both solutions can be combined into a "hybrid" recipe.

# Model Assisted Template Extractor (MATE)

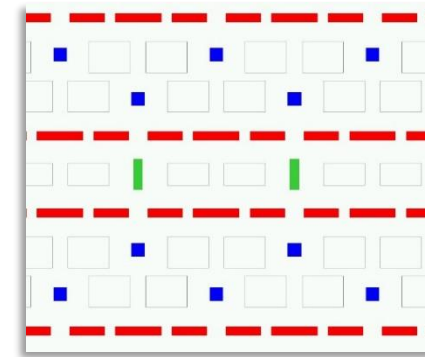
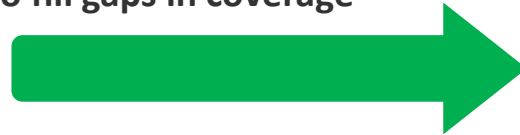
- MATE was targeted to accelerate the initial SRAF recipe generation, successfully reduced the recipe time from 5 days to 1 day.
- Detailed MATE flow is shown below:



# Current Manufacturing Strategy & Usage



Rule based SRAF templates created to “match” ILT SRAF placement, followed by model based template to fill gaps in coverage



**Complete SRAF coverage obtained using a hybrid combination of Precise Rule based templates + Model based FILL template**

- ✓ Comparable litho performance to ILT → pxOPC used as reference for Rule generation.
- ✓ Faster Recipe Creation → “MATE” Flow reduces rulesbased SRAF recipe creation time by 5X.
- ✓ Performance Benefits → Rule based runtime advantage.
- ✓ Customer’s Success → Multiple customers using MATE+CNSRAF today.

# OPC

Cell Swap

Fill

Retarget

Sraf

OPC

MRC

Fracture



# Mentor Solutions Span All Technology Needs

**NODE**  
250nm

180nm

150nm

130nm

110nm

90nm

65nm

45nm

32nm

20nm

10nm

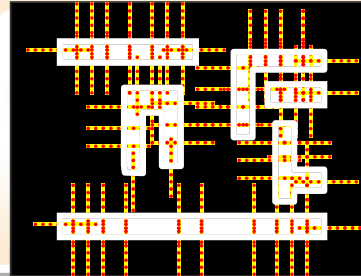
Rule-Based

**Calibre  
nmBIAS**

		Line Width					
		<=1	>.1<=.2	>.2<=.3	>.3<=.4	>.4<=.5	>.5
Spacing	<=1	0	0	0	0	0	0
	>.1<=.2	0	0	0	0	-10	-15
	>.2<=.3	0	0	0	-0.10	-10	-10
	>.3<=.4	0	0	0	0	-0.05	-10
	>.4<=.5	0	0	0	0	-0.05	-0.05
	>.5<=.6	0	.10	0.05	0.05	0	0
	>.6	0	.10	.10	0.05	0	0.05

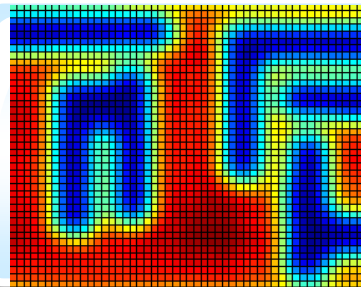
- 180 nm node
- Proximity effects are translated into rules
- Models for verification

**Calibre  
OPCpro**



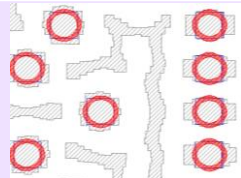
- First generation model-based OPC solution
- Sparse OPC solution for 180nm - 65nm nodes

**Calibre  
nmOPC**



- Dense OPC solution for 65nm node and smaller
- Grid based simulation

**Calibre  
pxOPC**

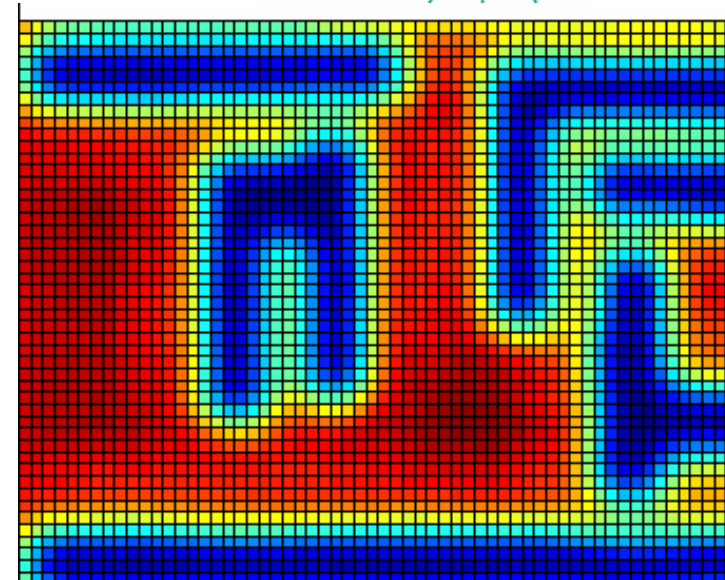
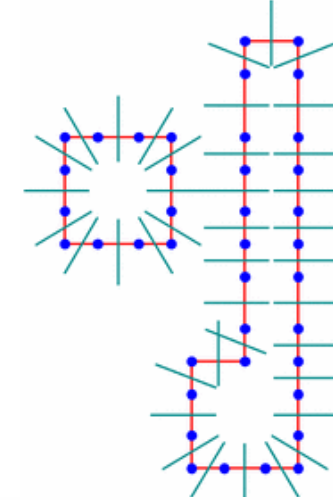


- Next Generation Inverse Lithography

Model-Based OPC Solutions

# Sparse vs Dense Simulation

- **OPCpro** Simulates and measures at sparse locations.
  - One simulation site per-fragment only.
- Convolution of SOCS Kernels in spatial domain.
- Run time depends on number of fragments.
  
- **nmOPC** Simulates on a grid.
  - Multiple simulation sites per fragment.
- Image is computed in frequency domain.
- Run time depends on area and pixel size.

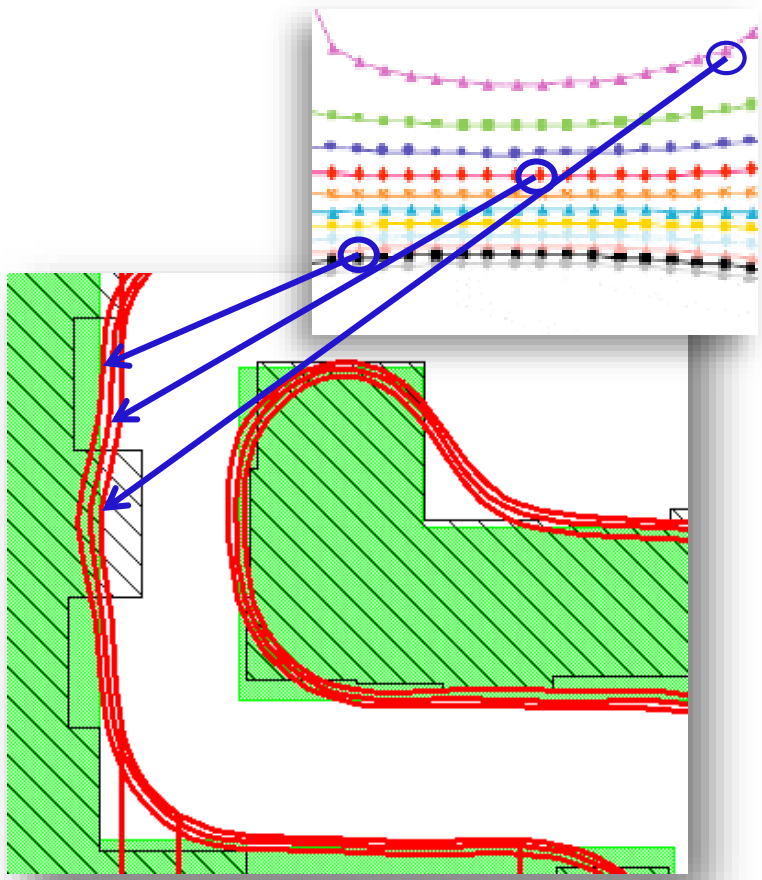
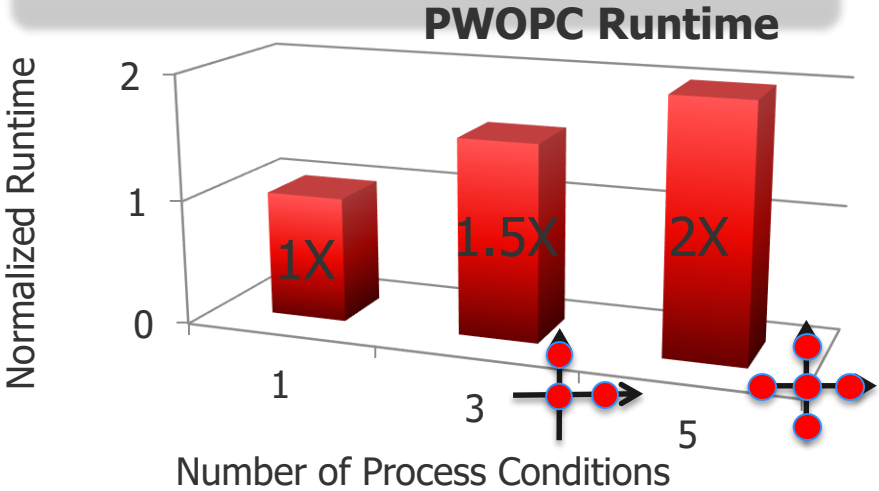


# PWOPC in Calibre nmOPC

- Maximizing process window by including dose/focus/mask conditions, and measuring/controlling CD width/space.

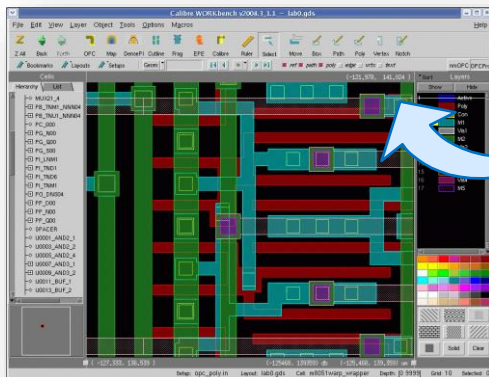
**Key Features**

- User-defined process conditions
- User-selectable tags
- User-controlled tolerances for:
  - Nominal condition EPE
  - Minimum CD width
  - Minimum CD space



# WORKbench Provides an Easy to Use Environment

## Calibre WORKbench

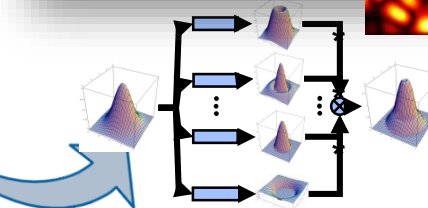
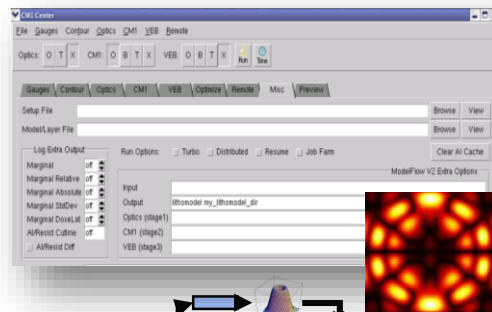
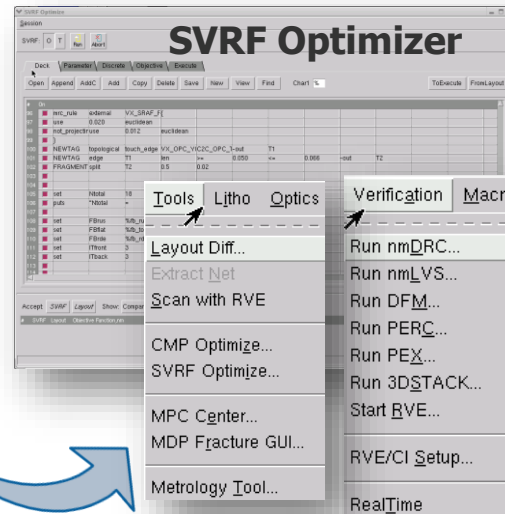


Fast and High-Capacity  
Hierarchical Layout Viewer

Interface with Calibre Tools  
for Rapid Testing

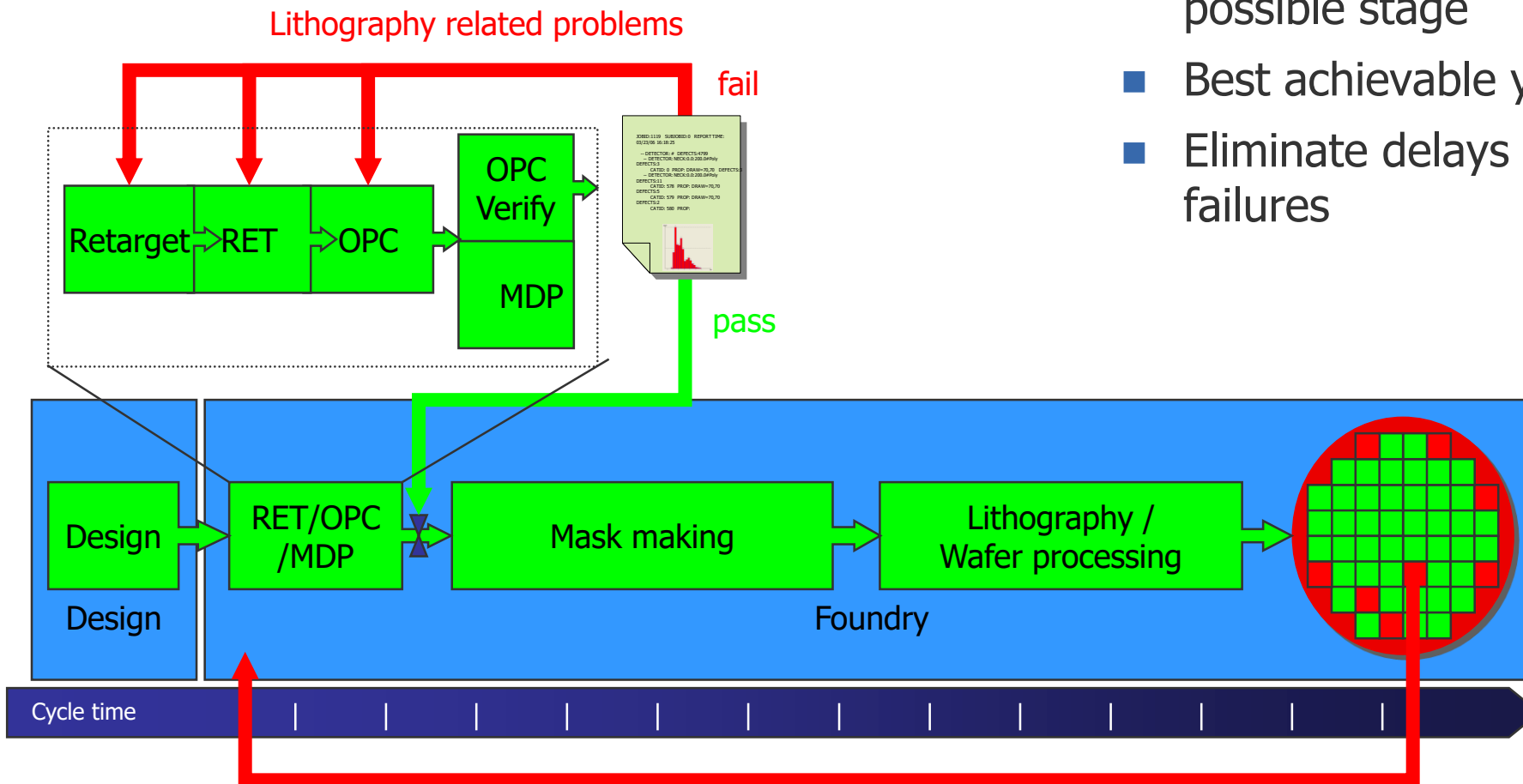
Litho Simulation and  
Recipe Development

Model Development



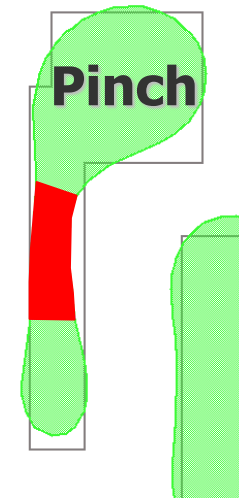
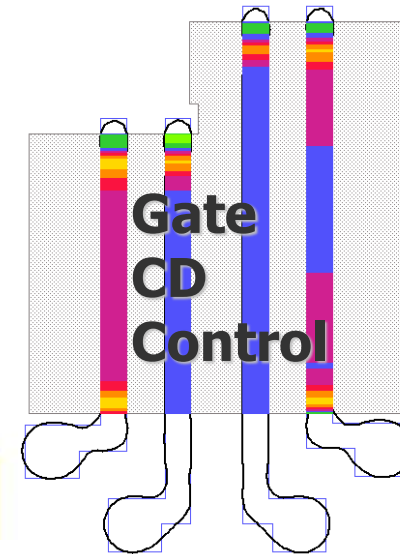
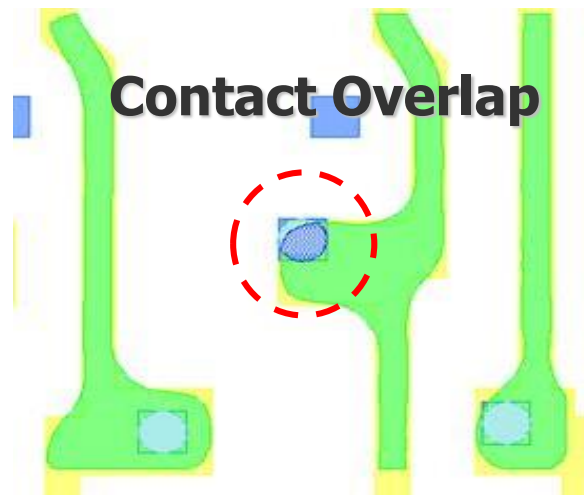
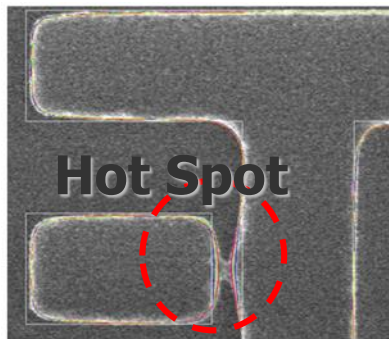
# OPCverify: Lithographic Verification Avoids Costly Re-Spins

- Problems caught at the earliest possible stage
- Best achievable yield without re-spin
- Eliminate delays caused by Litho failures



# Calibre OPCVerify Detects All Potential Yield Issues with Predictable TAT

- Full-chip simulation of the printed mask before tapeout is required to verify the litho process
- Optical dense simulation based engine guarantees 100% coverage
  - Any defect, anywhere on the chip, in any orientation



# MRC

Cell Swap

Fill

Retarget

Sraf

OPC

MRC

Fracture

# MRC: Just another set of DRC operations

```
LAYER AA 1
LAYER BB 2
LAYER CC 3

//Boolean operation / sizing
combined = ((SIZE AA BY 0.01 ) NOT (SIZE BB BY -0.01)) OR CC

// Model based OPC
combined_opc= LITHO OPC FILE "./setup_opc.in" combined

//MRC: width violation < 0.15, space violation < 0.15
violation_width { INTERNAL combined_opc < 0.15 REGION}
violation_space { EXTERNAL combined_opc < 0.15 REGION}

// Fracturing
fracture1 {FRACTURE MEBES combined_opc INSIDE OF 0 0 2500 4000 FILE [
magnify 4
mode 4
address_size 0.025
file_name TESTXXXXX.0
]
}
```



# FRACTURE

Cell Swap

Fill

Retarget

Sraf

OPC

MRC

Fracture

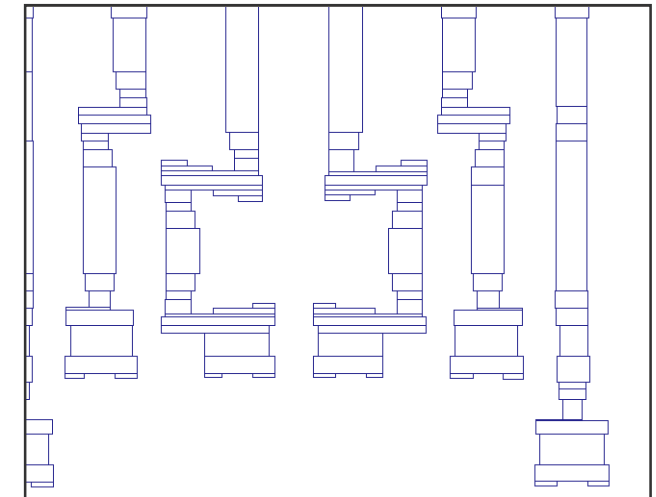
# Calibre MDP Overview

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- Introduced in 2002
- In production at advanced nodes – over 10,000 licenses deployed
- Hierarchical, integrated processing
- Highly scalable through direct I/O and section-based processing
- Embedded SVRF adds geometry processing within fracture command
- Comprehensive suite of support tools and utilities
- Multi-dose format support
- Current focus of enhancements
  - Continuous improvement of runtime, quality of results, file size, shot count, and scalability
  - Support for new fracture formats (such as multi-beam)

# Calibre MDP toolset

- Fracture – FRACTUREm, FRACTUREt,....
  - Hierarchical, hybrid and section based processing mode
  - Customized fracture algorithm for specific mask writing machines
  - Data quality control features
- MDPverify
  - Verification against the original input data for data integrity verification
  - <format>2db and <format>2<format> - e.g. MEBES2DB, MEBES2JEOL
  - Error post processing
- Viewing - MDPview
  - Viewing and overlay of pattern files and jobdecks with other formats
  - Disk based viewing and indexing functions for faster access
  - Support for extended MEBES jobdecks with OASIS pattern files
- MDP utilities
  - Multi-threaded translation of all formats into OASIS (<format>2oasis)
  - Global data quality statistics
- MDPstats
  - Data quality statistics – outside small features and pattern splits counting



Example MEBES data

# FLOW & ENGINE

Cell Swap

Fill

Retarget

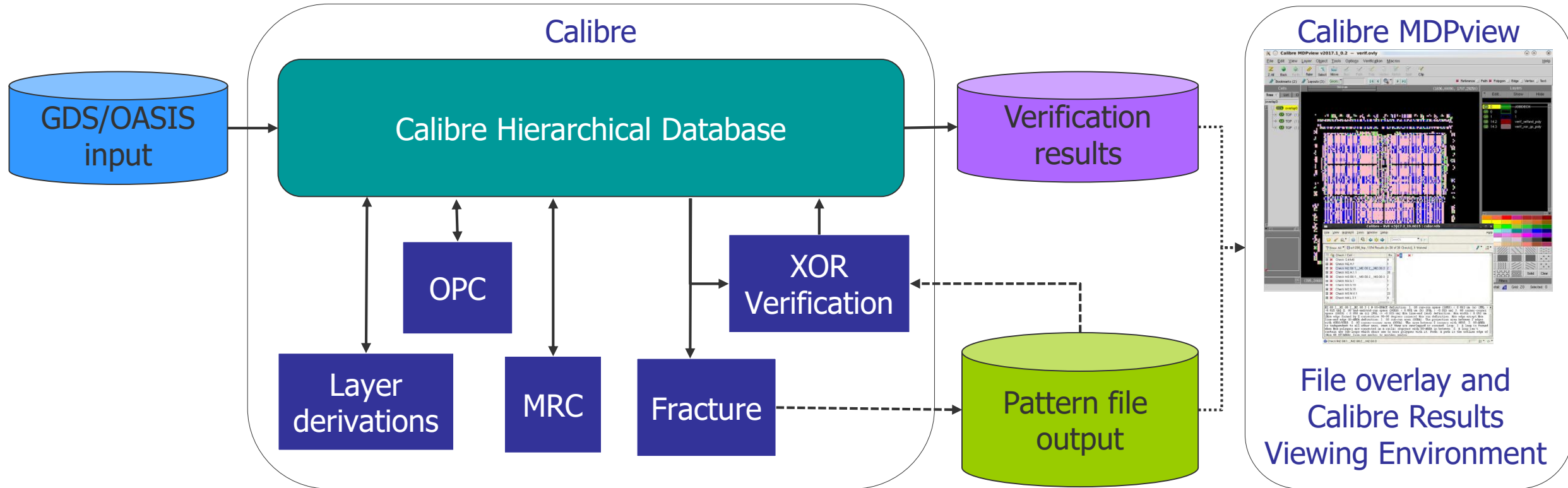
Sraf

OPC

MRC

Fracture

# Calibre OPC/MDP Integrated Flow



# Calibre PTO integrated run deck

```
LAYER AA 1  
LAYER BB 2  
LAYER CC 3
```

```
//Boolean operation / sizing  
combined = ((SIZE AA BY 0.01 ) NOT (SIZE BB BY -0.01)) OR CC
```

Boolean  
Operations

```
// Model based OPC  
combined_opc= LITHO OPC FILE "./setup_opc.in" combined
```

OPC  
Operations

```
//MRC: width violation < 0.15, space violation < 0.15  
violation_width { INTERNAL combined_opc < 0.15 REGION}  
violation_space { EXTERNAL combined_opc < 0.15 REGION}
```

Mask  
Rule Checking

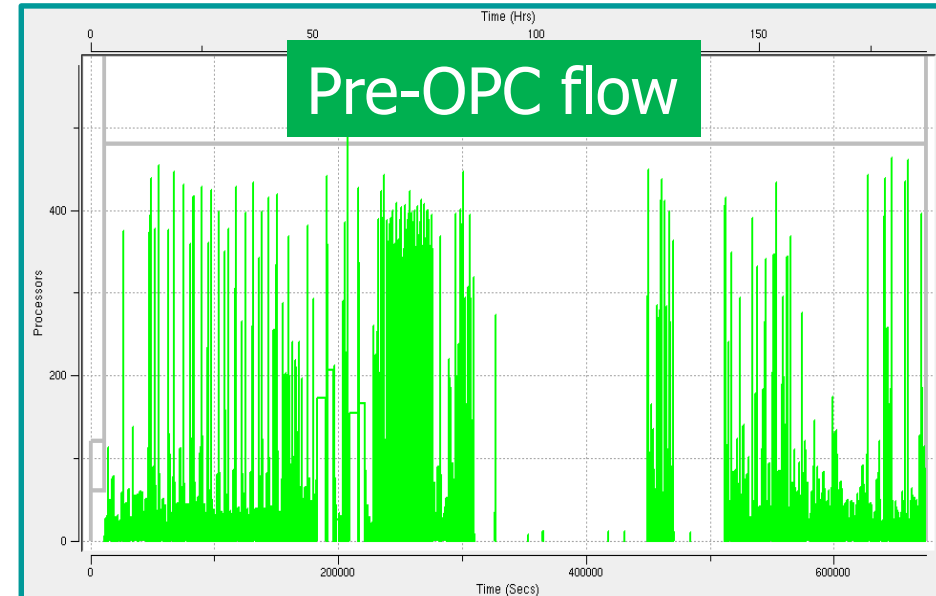
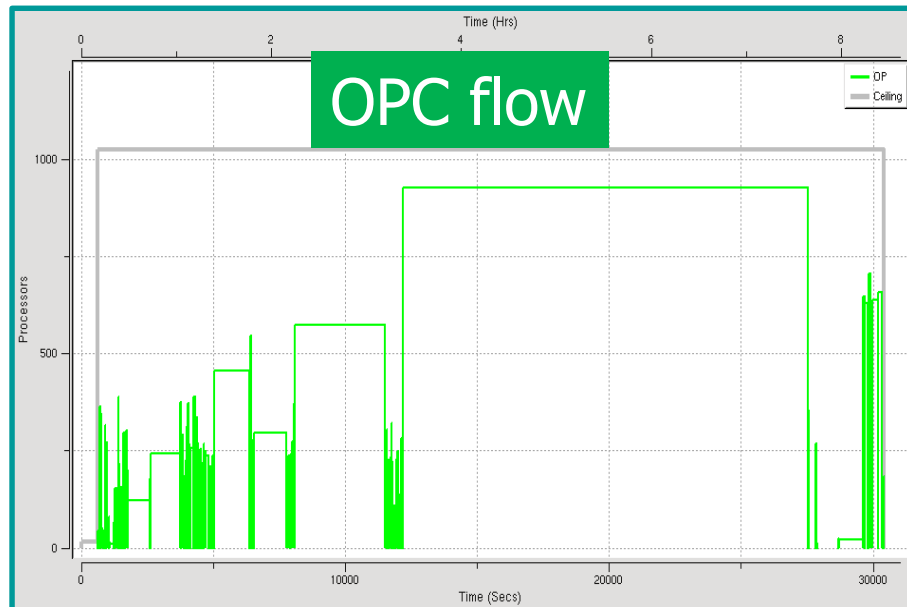
```
// Fracturing  
fracture1 {FRACTURE MEBES combined_opc INSIDE OF 0 0 2500 4000 FILE [  
magnify 4  
mode 4  
address_size 0.025  
file_name TESTXXXXX.0  
]  
}
```

Fracture  
Operation

- Internal layer passed from one operation to another
- Input: GDSII file - single read file operation
- Output: MEBES file - single write file operation, no GDSII file generated

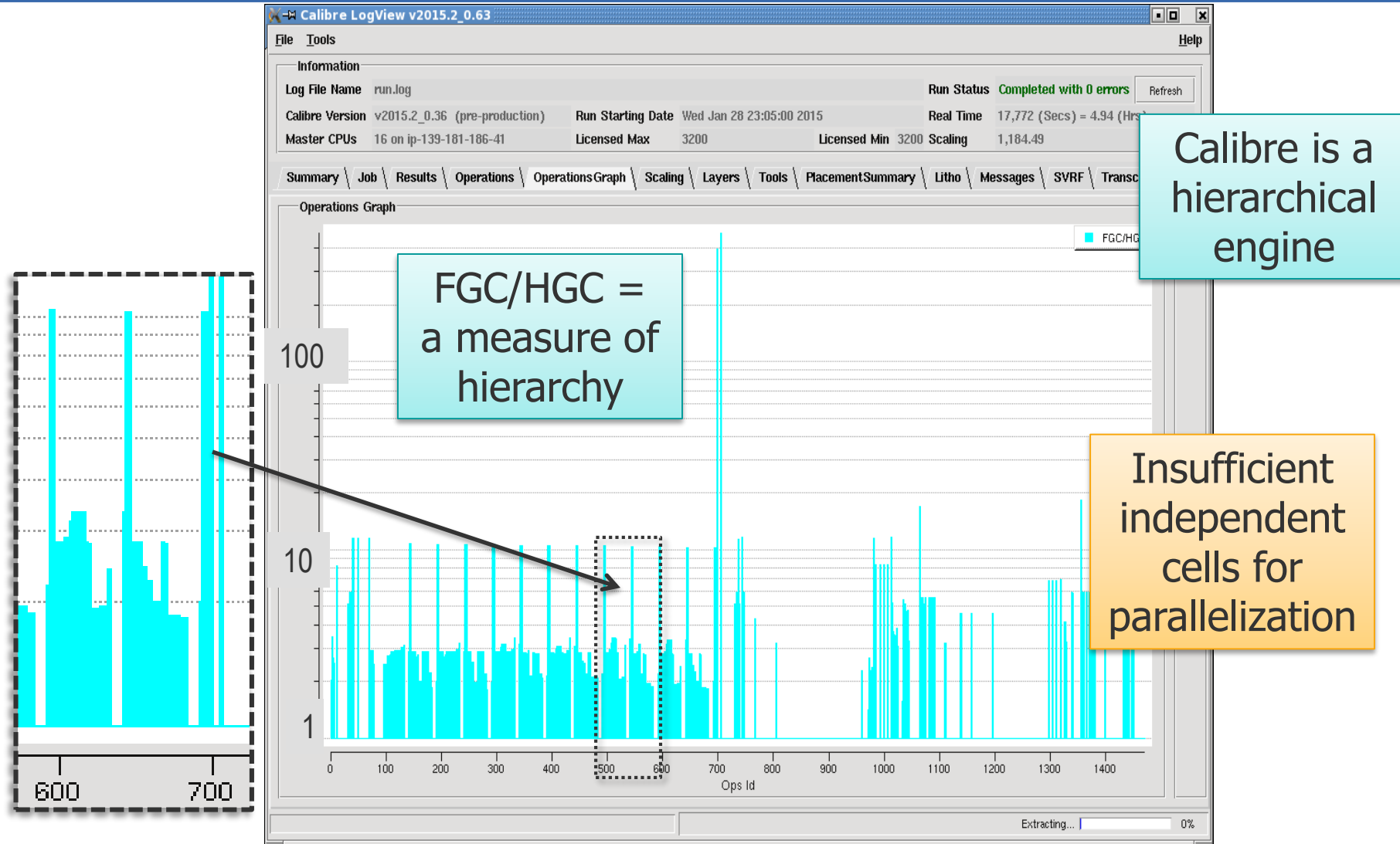
# Current Scalability Bottlenecks in PTO Flows

- Sequential execution of operations
  - Intermediate layers bottleneck
- Insufficient independent data for parallel computation
  - Hierarchical cells bottleneck
- Time to read data in/out.



# What Limits PTOF Scalability?

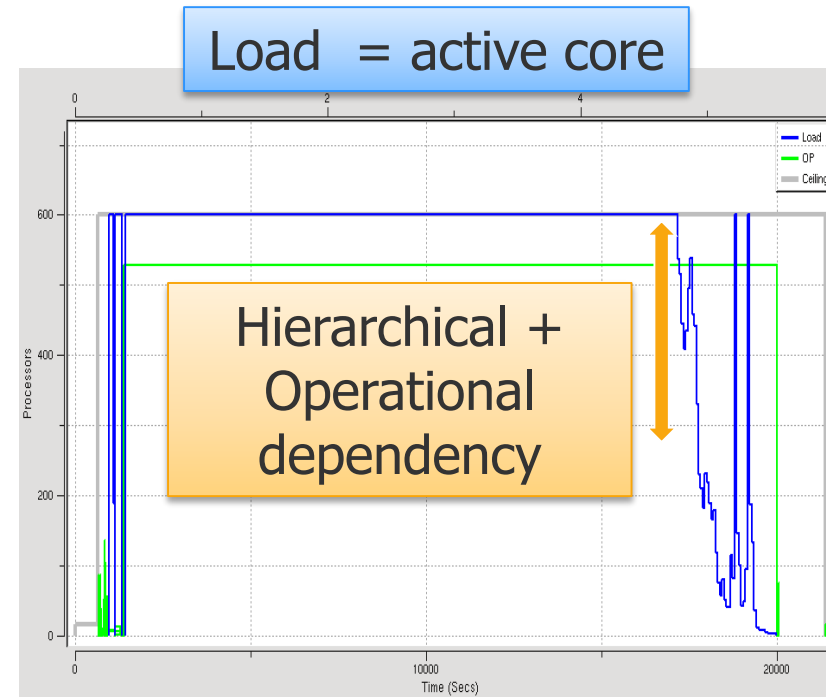
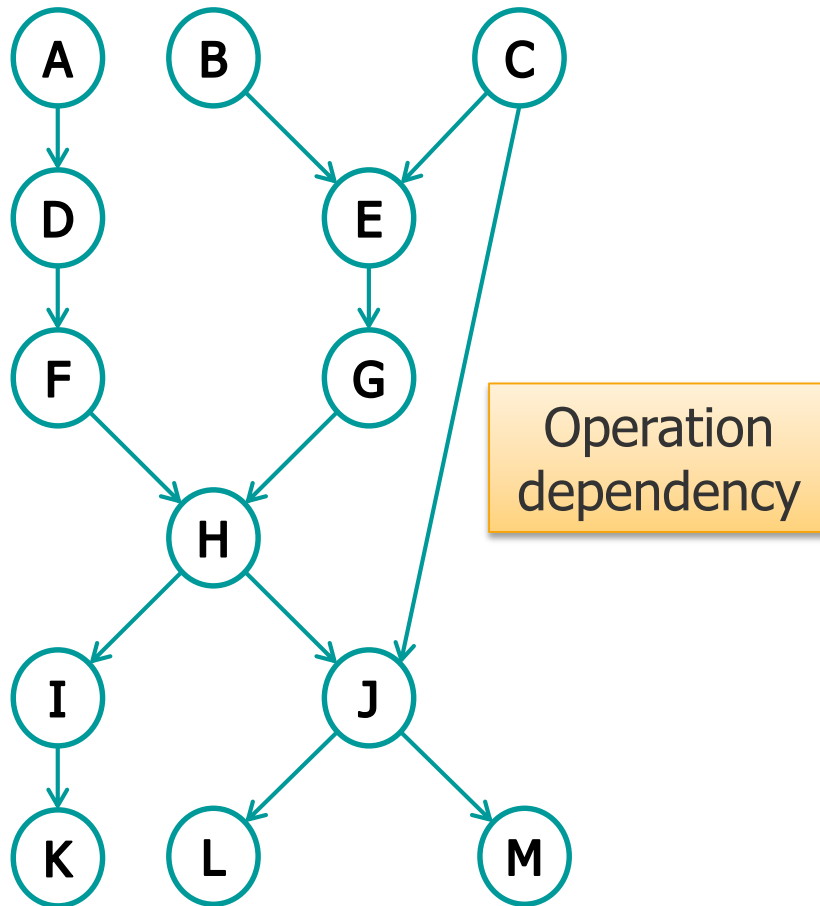
## [1] Insufficient Cells/Tiles for Partitioning





# What Limits PTOF Scalability?

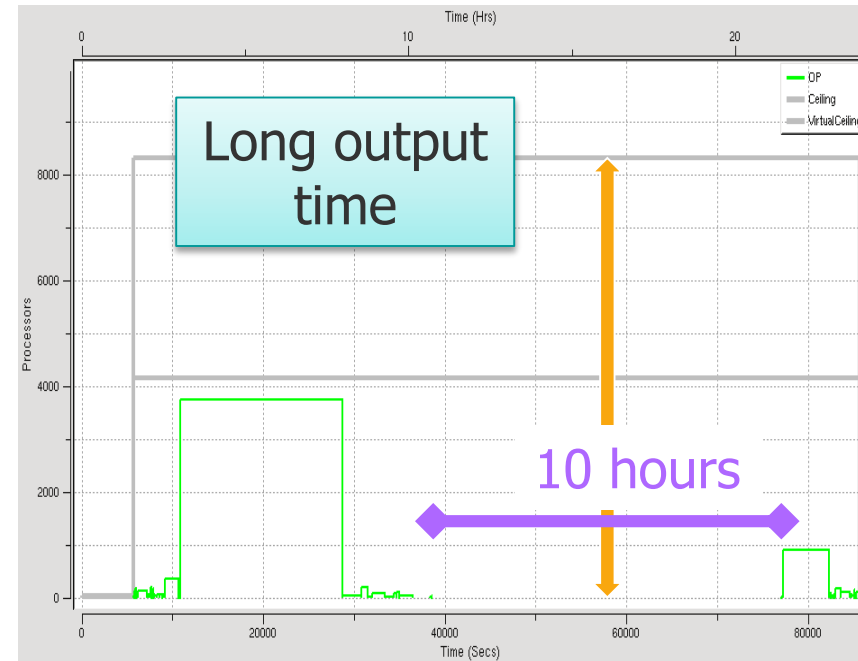
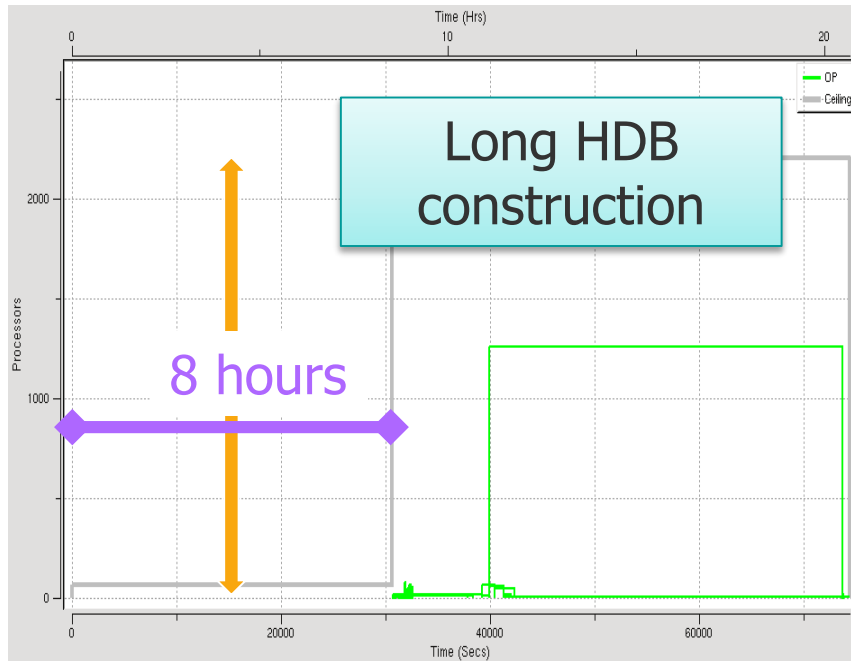
## [2] – Operation Dependency



# What Limits PTOF Scalability?

## [3] – Operations with Limited Scalability

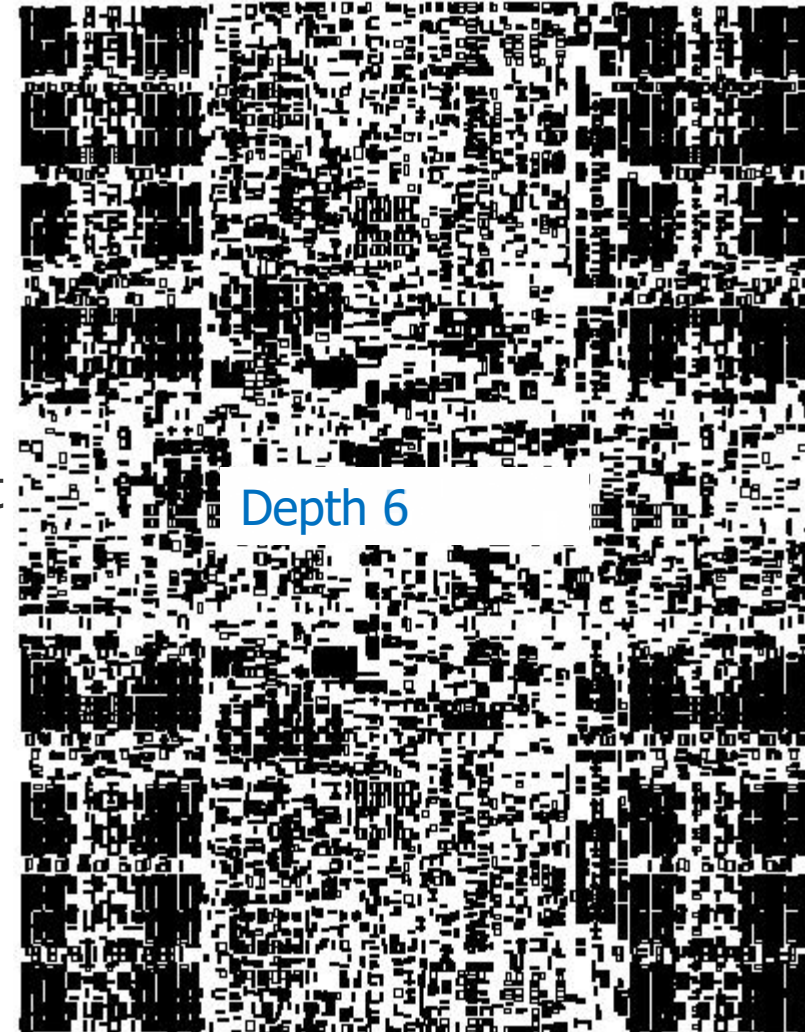
Some operations are intrinsically non-scalable



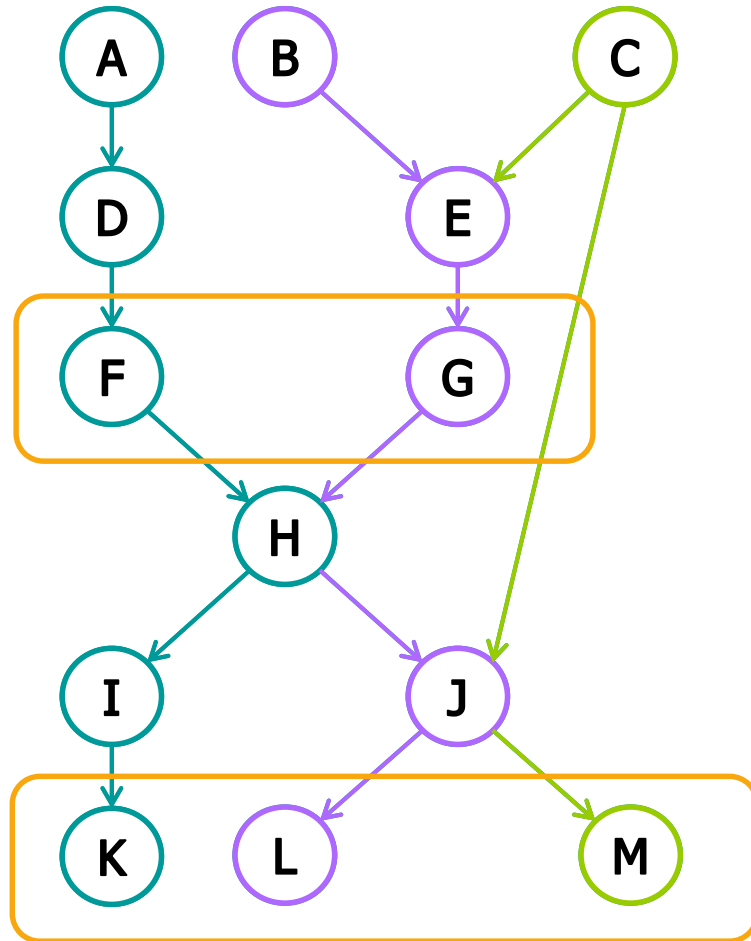
- Quite often, long-range operations like DP Decomposition, CONNECT, INTERACT are difficult to scale.

# PTOF Solutions: Quasi Flat/Hier Processing

- **Ultra Flex** – Hier maintained for cells inside 64x64 bins, otherwise are expanded until they can be placed into the bin.
  - “Mostly Flat”
  - Best for flat incoming data.
- **Turbo Flex** - Same as Ultra Flex except some cells crossing the 64x64 bins’ boundary are preserved.
  - “Mostly Hierarchical”
  - Best for hier. incoming data.
- Both provide more data partitions to distribute & scale.



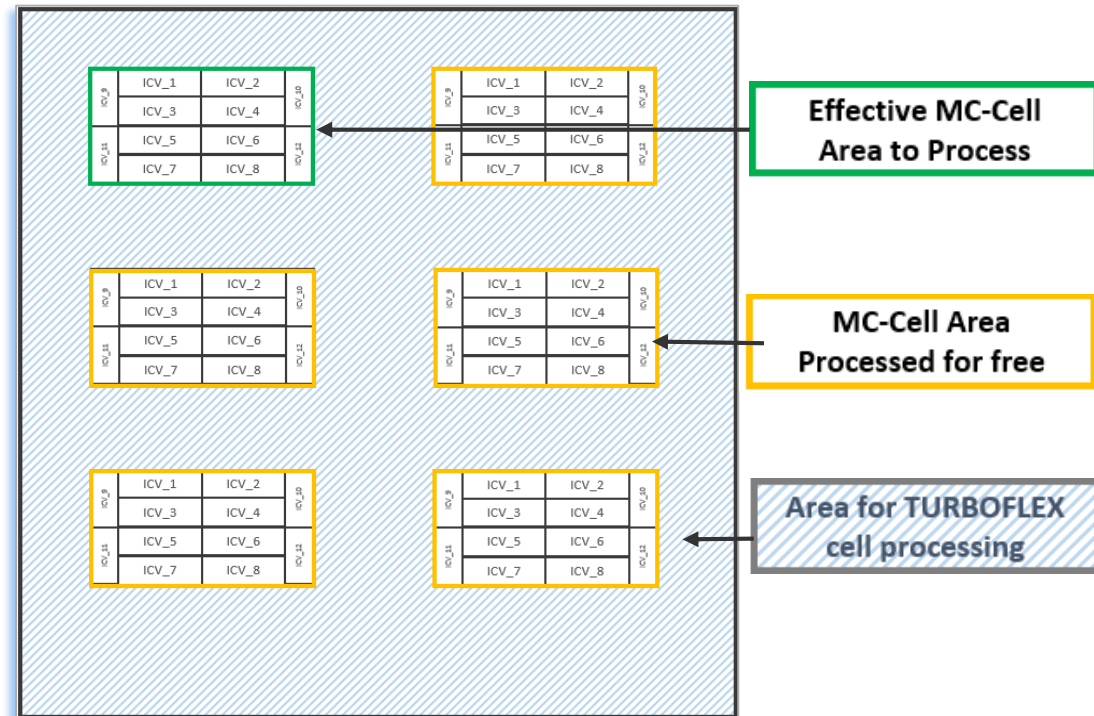
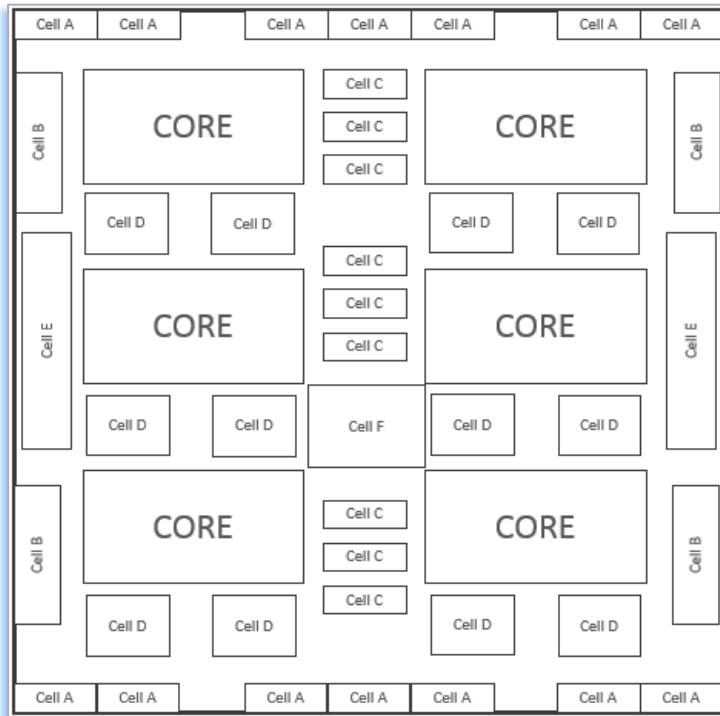
# PTOF Solutions: Hyperscaling



- Calibre engine processes the operations serially
  - There are some rearrangement to minimize the memory usage
- Independent operations can be processed in parallel
- Hyperscaling
  - Determine the independent operation paths
  - Create pseudo engines and process the independent paths in parallel

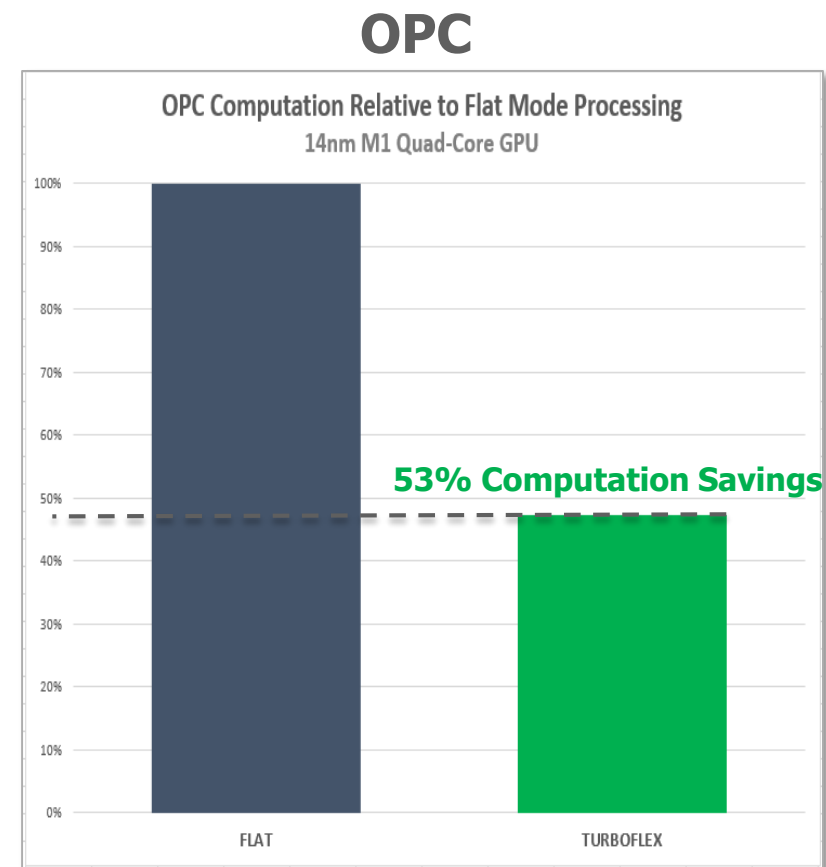
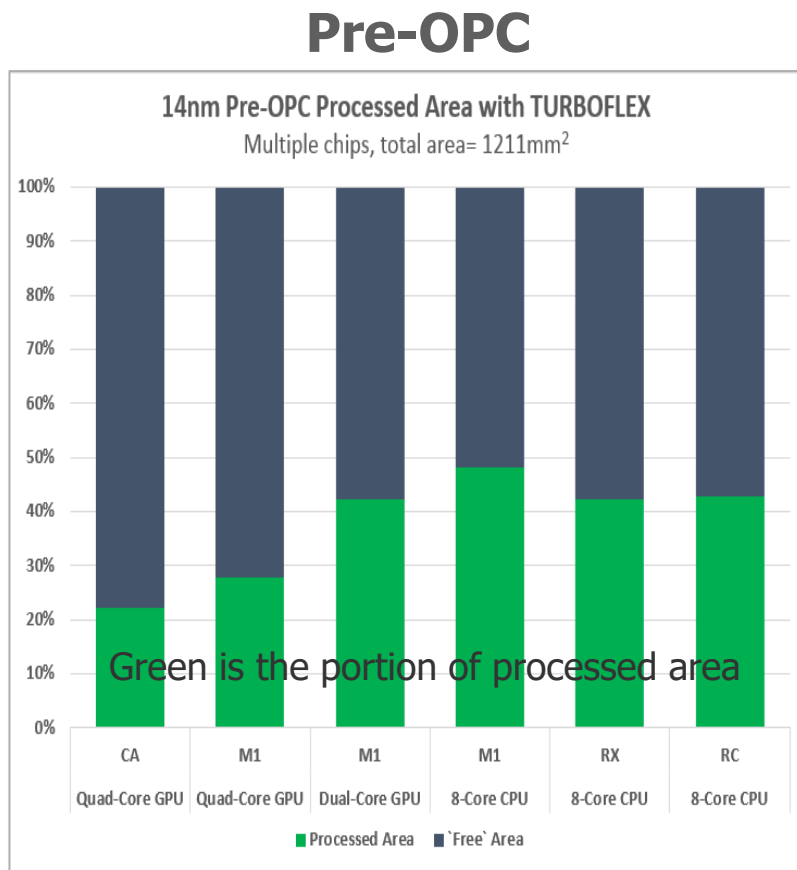
# Calibre PTOF solutions: TURBO FLEX with Multi-core cells

- Enhanced TURBO FLEX mode to detect multi-core instances
  - The multi-core cells are processed hierarchically, resulting in reduced effective area and consistent output across each core



# Calibre PTOF Solutions: Multi-Core Benefits Demonstrated

- Calibre nmOPC utilizes the processed area savings from multi-core benefit to significantly reduce computation time



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