

# Advancing Placement

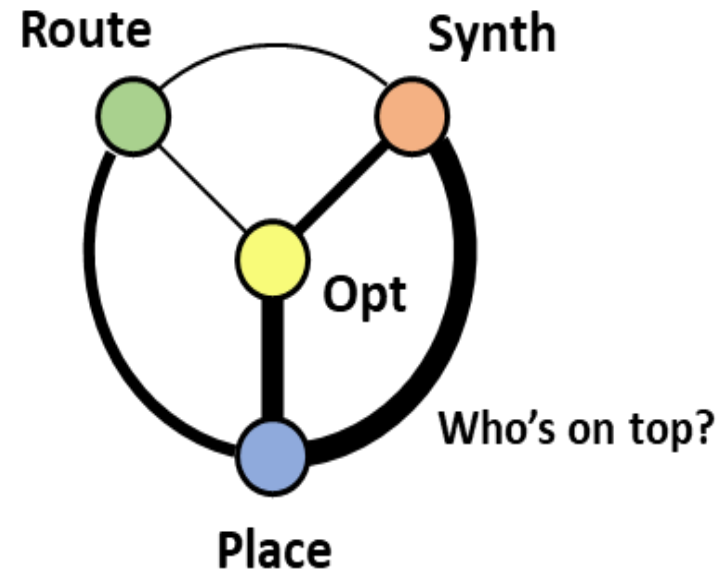
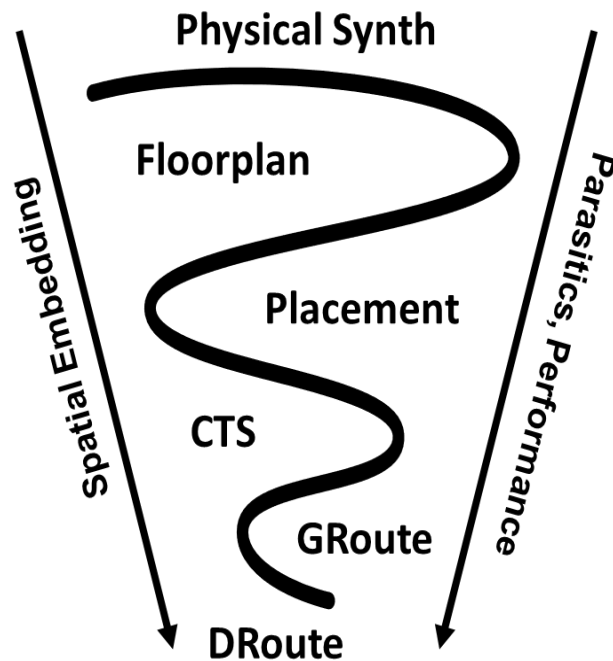
**ISPD-2021**  
**March 22, 2021**

---

Andrew B. Kahng  
Depts. of CSE and ECE  
UC San Diego  
[abk@ucsd.edu](mailto:abk@ucsd.edu)  
<https://vlsicad.ucsd.edu>

# Placement

- **Central to physical design: determines spatial embedding**
- **Conjointly optimized:** with logic, performance, routability, clock and power distribution, manufacturability, ...



- **Challenge 1:** Improve understanding of “Who’s on top?”

# Markov, Hu, Kim *Proceedings of the IEEE* 2015

- 50+ years of placement advances

Foundational Exploration		Modern Developments			Recent Progress
<1970-1980s	1980s-1990s	1990s-2010s			> 2010s
Partitioning	Simulated Annealing	Min-Cut (Multi-level)	Analytic Techniques		Analytic Techniques
			Quadratic/Force Directed	Nonlinear Optimization	
<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Breuer</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Dunlop and Kernighan</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Quadratic Assignment</div> <p><i>Resistive network based</i></p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Cheng and Kuh</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">PROUD</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Cadence/QPlace</div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">TimberWolf/VPR</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Dragon</div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">FengShui</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Capo</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Capo+Rooster</div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">GORDIAN</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">GORDIAN-L</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">BonnPlace</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">mFar</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Kraftwerk</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">FastPlace3/RQL</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Warp3</div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">APlace2</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">Naylor/Synopsys</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">NTUplace3</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">mPL6</div>	<p><i>Quadratic</i></p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">POLAR</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">SimPL/ComPLx</div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">MAPLE</div> <p><i>Nonlinear</i></p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;">ePlace/RePIAce</div>

# First ISPD Contest: Placement

---

- Placement contests have shaped the PD research agenda

**Table 1: History of academic placement contests.**

Year	Title
ISPD05	Placement
ISPD06	Placement
ISPD11	Routability-Driven Placement
DAC12	Routability-Driven Placement
ICCAD12	Design Hierarchy Aware Routability-Driven Placement
ICCAD13	Detailed Placement
ISPD14	Detailed Routing-Driven Placement
ICCAD14	Incremental Timing-Driven Placement
ISPD15	Blockage-Aware Detailed Routing-Driven Placement
ICCAD15	Incremental Timing-Driven Placement
ISPD16	Routability-Driven FPGA Placement
ISPD17	Clock-Aware FPGA Placement
ICCAD17	Multi-Deck Standard Cell Legalization
ISPD20	Wafer-Scale Deep Learning Accelerator Placement

# Advancing Placement: What's Left?

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward



# Advancing Placement

---

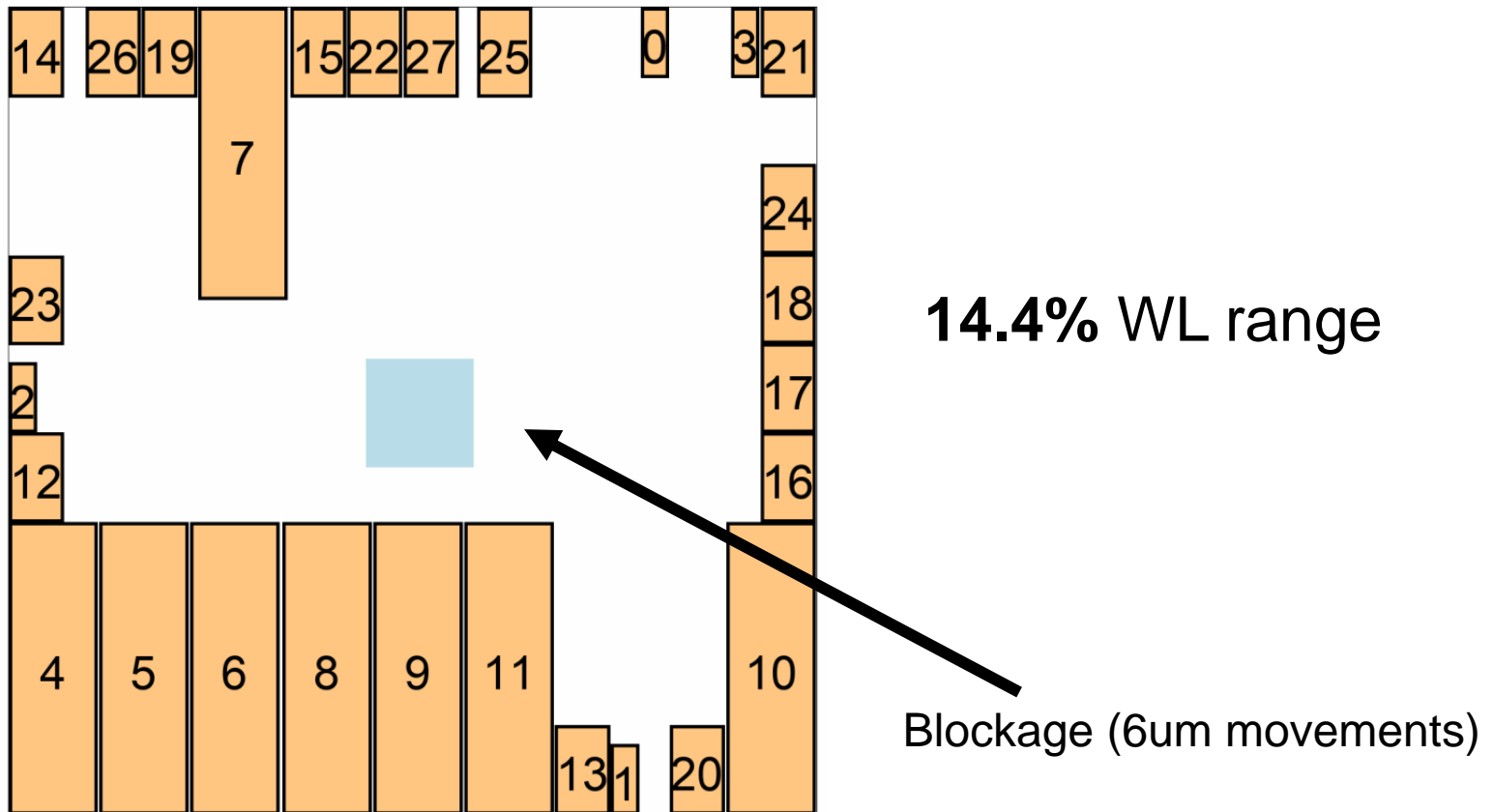
- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward

# Placement is Optimization

- “Quadratic assignment”
- Incredible complexity: objectives, constraints, scale

Foundational Exploration		Modern Developments			Recent Progress
<1970-1980s	1980s-1990s	1990s-2010s			> 2010s
Partitioning	Simulated Annealing	Min-Cut (Multi-level)	Analytic Techniques		Analytic Techniques
			Quadratic/Force Directed	Nonlinear Optimization	
Breuer	TimberWolf/VPR	FengShui	GORDIAN	APlace2	Quadratic POLAR
Dunlop and Kernighan	Dragon	Capo	GORDIAN-L	Naylor/Synopsys	SimPL/ComPLx
Quadratic Assignment		Capo+Rooster	BonnPlace	NTUplace3	MAPLE
<i>Resistive network based</i>			mFar	mPL6	<i>Nonlinear</i> ePlace/RePIace
Cheng and Kuh			Kraftwerk		
PROUD			FastPlace3/RQL		
Cadence/QPlace			Warp3		

# Predictable? Stable?



# Optimization: Predictability and Stability

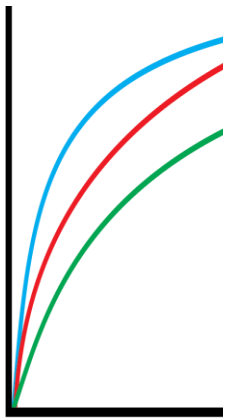
---

- **Challenge 2:** Develop **more predictable** placement optimization methods
- **Challenge 3:** Orchestrate placement methods on modern (parallel, distributed, AI) compute substrates with **predictability of outcomes (from ensembles of optimization runs)** as the driving criterion
- **Challenge 4:** Develop placement optimizers that have (provably) **smooth** behavior
- **Challenge 5:** Develop **incremental** and **re-entrant** placement methods that maintain from-scratch solution quality
- **Challenge 6:** Develop methods to solve the **tethered** placement problem

# Optimization: Closing the Suboptimality Gap

- Placement is optimization
  - Better, faster, cheaper – pick any two
- IC EDA: want all three at once
  - “Unfortunately, the runtime of ...”
- But the world has changed
  - Automation, cloud, ...

Foundational Exploration		Modern Developments			Recent Progress
<1970-1980s	1980s-1990s	1990s-2010s			> 2010s
Partitioning	Simulated Annealing	Min-Cut (Multi-level)	Analytic Techniques		Analytic Techniques
			Quadratic/Force Directed	Nonlinear Optimization	
Breuer	TimberWolf/VPR	FengShui	GORDIAN	APlace2	POLAR
Dunlop and Kernighan	Dragon	Capo	GORDIAN-L	Naylor/Synopsys	SimPL/ComPLx
Quadratic Assignment		Capo+Rooster	BonnPlace	NTUPlace3	MAPLE
<i>Resistive network based</i>			mFar	mPL6	<i>Nonlinear</i>
Cheng and Kuh			Kraftwerk		ePlace/RePIAce
PROUD			FastPlace3/RQL		
Cadence/QPlace			Warp3		



**Question:** If you give your P&R tool 3 extra days of runtime, would it know how to use this extra time?

**Question:** If you could run 10,000 copies of your P&R tool at the same time, what QOR improvement **should** you expect?

# Optimization: Closing the Suboptimality Gap

---

## Suboptimality ... in what sense?

- Need proper aiming points for research
- “Core and clean”, updated problem statements

## Benchmarking

- “Real” benchmarks = obfuscated, incomplete, non-vertical, old...
  - RISC-V, CHIPS Alliance, OpenHW Group, DARPA POSH, Google-SkyWater, ... = a good start, but these aren't drivers
- “Artificial” benchmarks = tiptoeing between realism, known optimal solution quality, scalability ...
  - 30+ years of NCSU/MCNC, planted solutions (PEKO), perturbed real designs (ZCNT), matching to topological parameters (gnl, circ/gen, ...) ...

## With modern compute resource

# Optimization: Closing the Suboptimality Gap

---

- **Challenge 7:** Update **core** placement optimization formulations, and develop long-lived benchmarks and solution criteria
- **Challenge 8:** Develop and widely adopt generators and suites of **artificial testcases that are representative (to optimizers)** of diverse design types and future instance complexities
- **Challenge 9:** Develop and improve placement methods with **solution quality that increases monotonically with the given “footprint”** (threads  $\times$  runtime) of computational resource
- **Challenge 10:** Establish an **“Underwriters Laboratories”** for measurement, benchmarking of IC design automation and designs

# Advancing Placement

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward

# Placement Optimization Has Context

---

- **Tightly integrated** optimizations, **common analysis engines**
  - Need on-demand constructive estimations, reduced miscorrelations
- **Art of Co-Optimization:** “What should the placer know, and when should the placer know it?”
  - WL → timing → density → congestion → non-overlap → pin accessibility
  - Constraint or objective? **overlap or setup violation = weight or penalty?**
  - Treat or mask or ignore (until later)? **edge-type conflict, in-context pin access**
- **Co-Optimization through Co-Operation**
  - **Interleaving or alternation** that leverages tight integration **cf. “fusion”**
  - Find viable solutions to take forward: physical synthesis, floorplan
  - Find **fixed points** in chicken-egg loops: PDN, clock skew
  - **Tight loops:** with global routing or with detailed routing

# Co-Optimization and Co-Operation

---

- **Challenge 11**: Develop improved **congestion** formulations for use in analytic placement
- **Challenge 12**: Improve foundational understanding of how objective function estimation **accuracy**, constraint **relaxation** and instance **evolution** determine solution **quality**
- **Challenge 13**: Develop stronger, distributable “**heavy optimizations**” in detailed placement
- **Challenge 14**: Develop methods to directly solve for the **fixed point** of simultaneous “**chicken-egg**” optimizations
- **Challenge 15**: Develop improved conjoint optimization of **placement and clock** distribution.
- **Challenge 16**: Develop foundational understanding of placement-centered co-optimizations

# Advancing Placement

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward

# “New” Foci

---

## Physical context

- 3D
- “Island-heavy”

## Design context

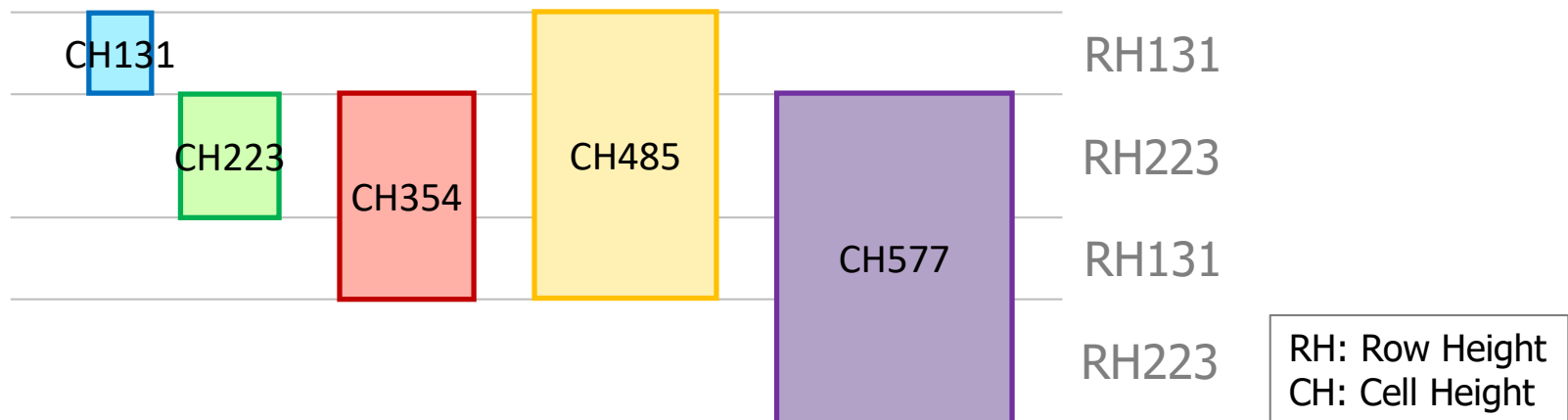
- Extreme memory-dominance
- System interconnect

## Specializations

- Datapath
- + analog, IO, die-package, reliability-driven, ...

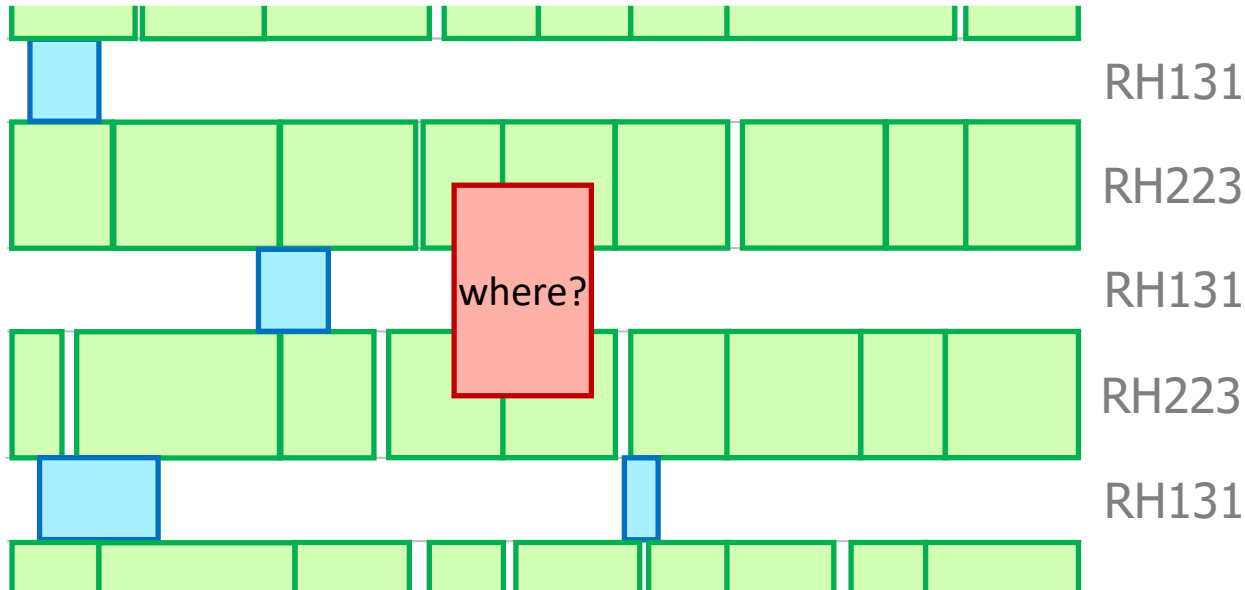
# “Island-Heavy”: Multiple Row and Cell Heights

- Consequence of density **and** performance scaling
- Simplest Example: Two Types of Rows
  - Tall row Height is **not** a multiple of Short row Height
  - Pattern: A-B-A-B-A-B
- **Two** Types of Single-Height Cells
  - CH131 and CH223
- **Several** Possible Types of Multi-Height Cells
  - CH354 (131+223), CH485 (131+223+131), CH577 (223+131+223), ...



# Floorplanning, Density, Puzzle-Fitting, ...

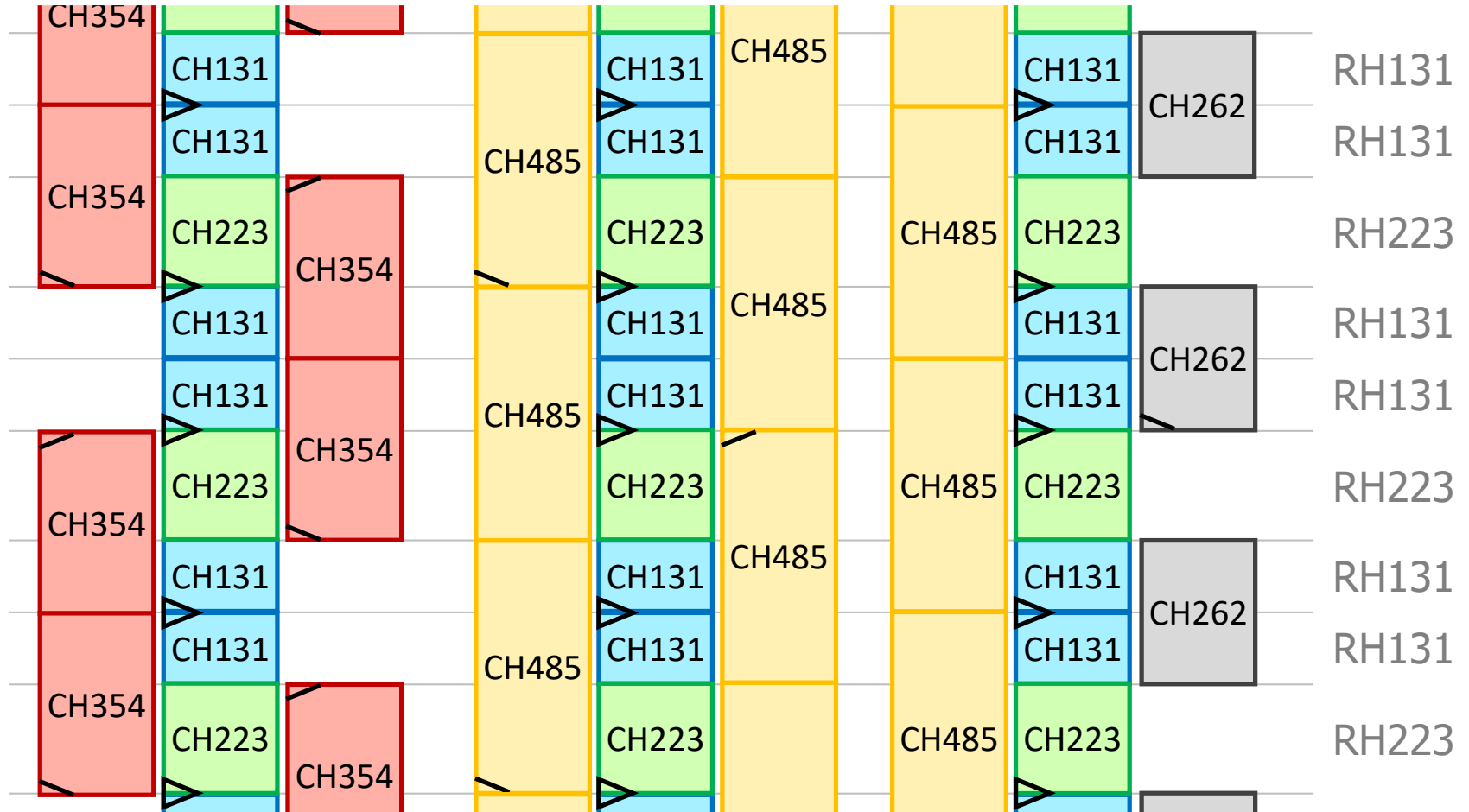
- Global placement density control for both Short and Tall rows



- Local density can be bad even if overall density looks good
- Whitespace distribution must be able to absorb changes
- *How to control cell movement during detailed placement?*
- *How to control congestion?*

# Can Get Much More Complicated ...

- **A-A-B-A-A-B (shown)**, or A-B-C-A-B-C, or A-B-C-B-A, or ...
- Detailed placement **complexity** (DRC, pin accessibility, etc.)



# “New” Foci

---

## Physical Context

- **Challenge 17:** Develop “true 3D” placement
- **Challenge 18:** Develop techniques for “island-heavy” placement

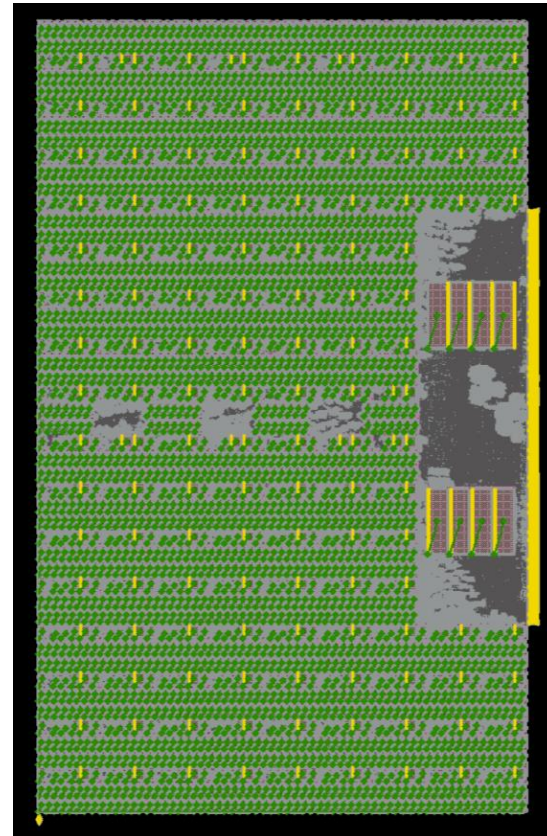
# Extreme Memory-Dominance

- **AI and Machine Learning accelerators**

- Can have very high fractions of die or block area occupied by SRAM and register file instances
- Can have thousands of SRAM macros
- Examples from DARPA Real Time Machine Learning project



systolic\_array (256 macros)



tabla\_wrapper  
(2488 macros)

# “New” Foci

---

## Physical Context

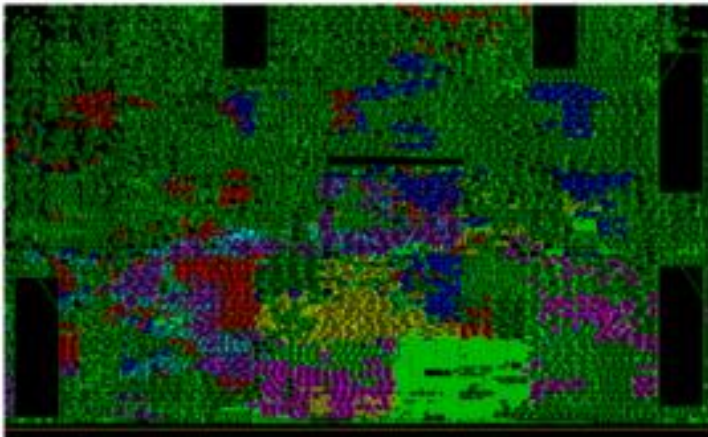
- **Challenge 17:** Develop “true 3D” placement
- **Challenge 18:** Develop techniques for “island-heavy” placement

## Design Context

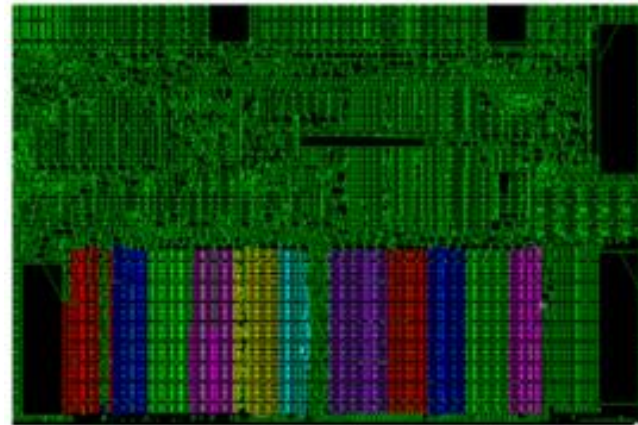
- **Challenge 19:** Develop performance-driven macro packing and floorplan automation that matches or surpasses human solution quality
- **Challenge 20:** Develop system interconnect-savvy SOC floorplan optimizations with expert-human solution quality

# Regular Structures in Datapaths

- Datapaths → highly regular structures embedded in the synthesized netlist
- Extracting and placing in aligned rows and columns can improve PPA
  - Latency and skew in clock distribution
  - Wiring predictability for bussed nets
- PPA gains are multiplied in tiled designs
- Opportunity for **automation** to achieve custom QOR



Traditional Placement



Structured Placement

Images copyright Cadence Design Systems, Inc. From Cadence SDP documentation:

[http://free-online-ebooks.appspot.com/enc/14.17/soceUG/Using\\_Structured\\_Data\\_Paths.html](http://free-online-ebooks.appspot.com/enc/14.17/soceUG/Using_Structured_Data_Paths.html)

# “New” Foci

---

## Physical Context

- **Challenge 17:** Develop “true 3D” placement
- **Challenge 18:** Develop techniques for “island-heavy” placement

## Design Context

- **Challenge 19:** Develop performance-driven macro packing and floorplan automation that matches or surpasses human solution quality
- **Challenge 20:** Develop system interconnect-savvy SOC floorplan optimizations with expert-human solution quality

## Specializations

- **Challenge 21:** Develop niche placement automations that remove human expertise bottlenecks
- **Challenge 22:** Develop datapath placement automation that surpasses human-directed solution quality

# Advancing Placement

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward

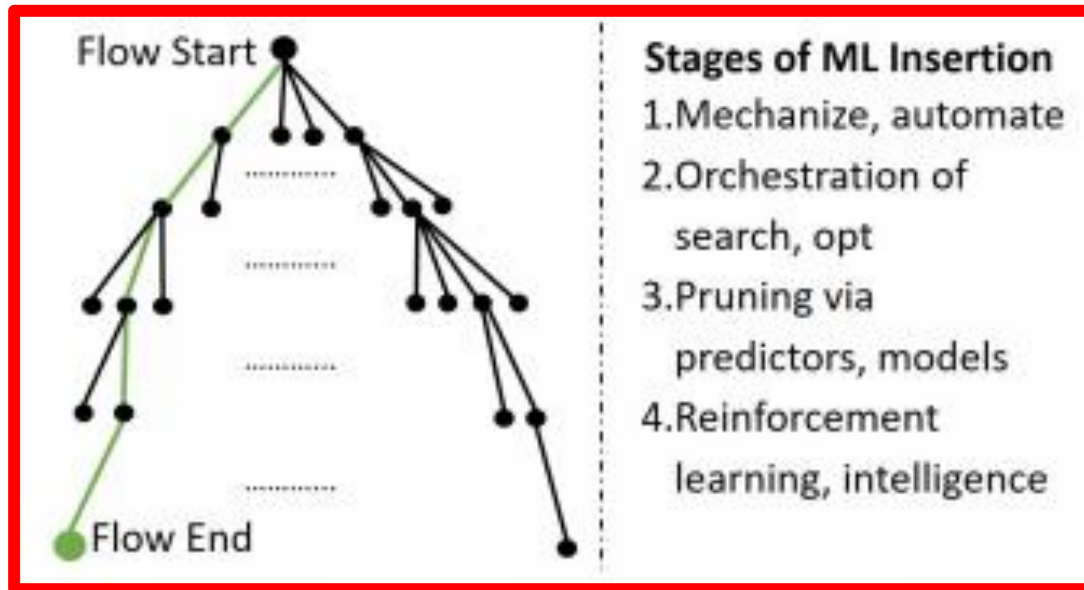
# Why Machine Learning

## See ahead

Avoid doomed runs  
Use resources better

## Capture expertise

Transfer/imitation  
Algorithm alignment



ISPD-2018

What you can't predict, you guardband

What you don't explore, you leave on the table

# Learning and Placement

---

- Tremendous progress since, e.g., ISPD-2018
  - MLCAD Workshop, IEEE CEDDA DAWN, Huang et al. “Machine Learning for Electronic Design Automation: A Survey” (*ACM TODAES*, 2021)
  - **Many great works**
  - **Many remaining challenges**
- Learning **objectives** **what to optimize?**
- **Smart flow** and flow control **how to optimize within “box” of resources**
- **Embedding and clustering** **distance measures, complexity reductions**
- **Deep learning** for placement **Google Brain!**
- Domain expertise **algorithm alignment, transfer/imitation... but... Bitter Lesson?**
- **AI hardware** **DREAMPlace!**
- Open source ...

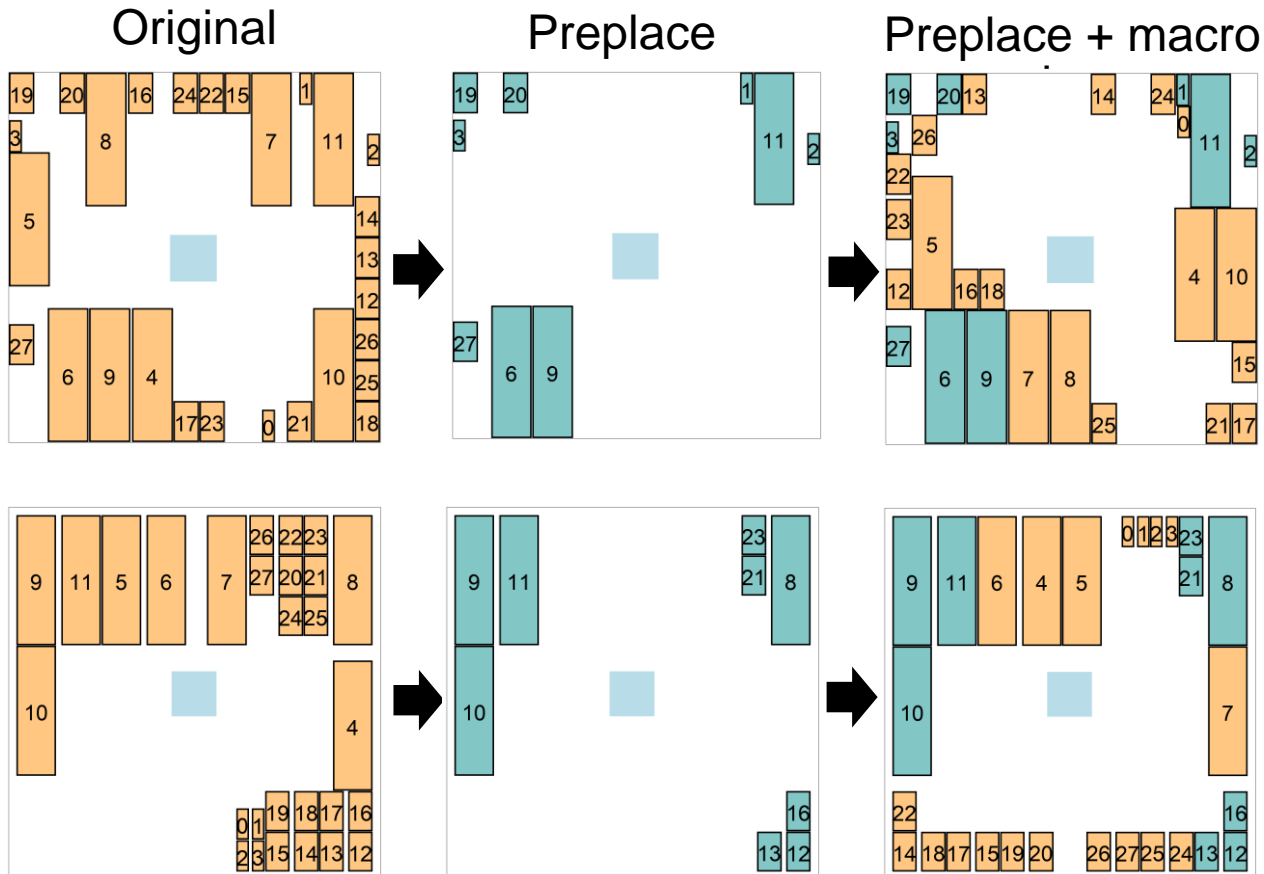
# Learning and Placement

---

- **Challenge 23:** Develop accurate predictors of closed-source tool outcomes using open-source tools
- **Challenge 24:** Find quantum leaps in solution quality and speed at the nexus of ML and placement
- **Challenge 25:** Launch organized, multi-entity metrics collection to support ML studies and contests.

# “Be Careful What You Ask For”

- What if I know some of the macro placer’s solution in advance ...



- P&R\_1**  
~ 3.5%  $\Delta$ WL,  
different structure

- P&R\_2**  
~ 0.5%  $\Delta$ WL,  
different structure

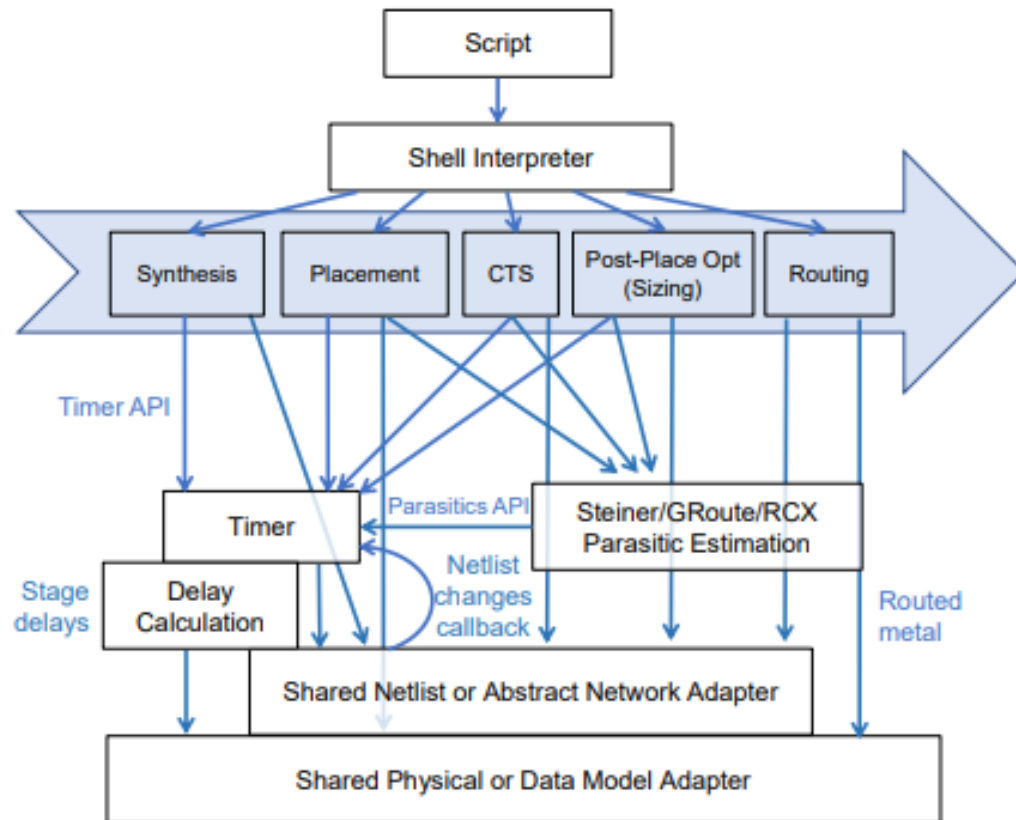
# Advancing Placement

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward

# Support for Placement Research

- Flow-scale context and open source
  - IEEE CEDDA DATC Robust Design Flow: <https://github.com/ieee-ceda-datc>
  - RTL-to-GDS backplane for research includes open-source DB, STA



**Figure 4: OpenROAD shared netlist architecture.**

# Support for Placement Research

- Metrics collection and ML enablement
  - Standard terms and semantics, underlying data model, implementation, ...
  - “Metrics4ML” repo: <https://github.com/ieee-ceda-datc/datc-rdf-Metrics4ML>

### Metrics Naming Convention

Metrics naming has been organized based on design stage, metric category, metric name and modifiers to have a standardized mechanism of metrics reporting. Below figure shows an example of metrics naming convention in the current OpenROAD, based on universes of flow stage names, nouns at run-level and tool metric-level, and modifiers.

	Stage	Metric Category	Metric Name	Modifier	Modifier	value	Threshold	Full Metric name
14	synth	area	stdcell	area	float			synth.area.stdcell.area
15	synth	area	macros	count	int			synth.area.macros.count
16	synth	area	macros	area	float			synth.area.macros.area
17	synth	area	sequential	count	int			synth.area.sequential.count
18	synth	area	sequential	area	float			synth.area.sequential.area
19	synth	area	combinational	count	int			synth.area.combinational.count
20	synth	area	combinational	area	string			synth.area.combinational.area
21	synth	timing	wms	worst	string			synth.timing.wms.worst
22	synth	timing	tns	total	string			synth.timing.tns.total
23	constraints	clocks	count		int			constraints.clocks.count
24	constraints	clocks	details		list			constraints.clocks.details
25	floorplan	area	stdcell	count	int			floorplan.area.stdcell.count
26	floorplan	area	stdcell	area	float			floorplan.area.stdcell.area

— globalplace\_area\_wirelength\_est = post-global placement estimated wirelength  
— droute\_power\_leakage\_sequential = post-route leakage power for sequential cells

A sample of the logger output and extraction to metrics dashboard from the .json (or .html) is shown in the figure below.

```

[INFO GRT-0018] Total wirelength: 1107513 um.
[INFO RSZ-0027] Inserted 258 input buffers.
[INFO RSZ-0028] Inserted 129 output buffers.
[INFO RSZ-0039] Resized 10777 instances.
report_tns
-----
[INFO RSZ-0052] tns -0.00
report_wns
-----
[INFO RSZ-0053] wns 0.00
[INFO RSZ-0048] Design area 121321 u^2.
                    
```

globalplace_area_wirelength_est	1107513
placeopt_area_buffer_input	258
placeopt_area_buffer_output	129
placeopt_area_resize_inst	10777
placeopt_timing_tns_total	-0
placeopt_timing_wns_worst	0
placeopt_area_inst_area	121321 u^2

log file
metrics.json (or .html)

# Conclusion: Looking Back, Looking Forward

---

## Looking Back

- **Exciting advances** since Markov et al. (2015)
  - RDF-2020 and industry-compatible “full flow”
  - Focus at a nexus of learning and optimization
  - Google Brain: deep RL for macro placement
  - UT Austin and Nvidia: DREAMPlace and ABCDPlace
- **The sweep of history**
  - Influence of ISPD-2005 contest, key ideas and papers clearer today [\[115\]](#)

## Looking Forward

- Return to optimization roots
  - Learning-enabled, adaptive, self-tuning
  - Distributed, federated in the cloud
- Culture changes
  - Open source + benchmarking, re-commit to closing the suboptimality gap

# Advancing Placement: What's Left?

---

- **Placement Optimization**
  - Predictability and Stability
  - Closing the Suboptimality Gap
- **Co-Optimization and Co-Operation**
  - The Art of Co-Optimization
  - Co-Optimization Through Co-Operation
- **“New” Foci for Placement**
  - Physical Context
  - Design Context
  - Specializations
- **Learning and Placement**
- **Support for Placement Research**
  - Flow-scale Context and Open Source
  - Metrics Collection and ML Enablement
- **Conclusions:** Looking back and looking forward



# THANK YOU !

Many thanks are due to colleagues who generously provided thoughts on futures for placement which have been incorporated here: David Chinnery, Dennis Huang, Ilgweon Kang, Stefanus Mantik, Igor Markov, Siddhartha Nath, David Pan, Ravi Varadarajan and Joe Shinnerl. Thanks are also due to the ISPD-2021 organizers for inviting this paper and talk.

---

**Support:** ABKGroup research is supported by NSF CCF-1564302, DARPA HR0011-18-2-0032 and HR0011-19-S-0037, Samsung, Qualcomm, NXP Semiconductors, Mentor Graphics, and the C-DEN Center.

**Links:** (i) OpenROAD Project: [readthedocs](#), [website](#), [GitHub](#) ; (ii) set of [basic links](#) on ML in EDA / IC design from my group; (iii) talks are generally posted as .PPTX source with speaker notes at <https://vlsicad.ucsd.edu/>