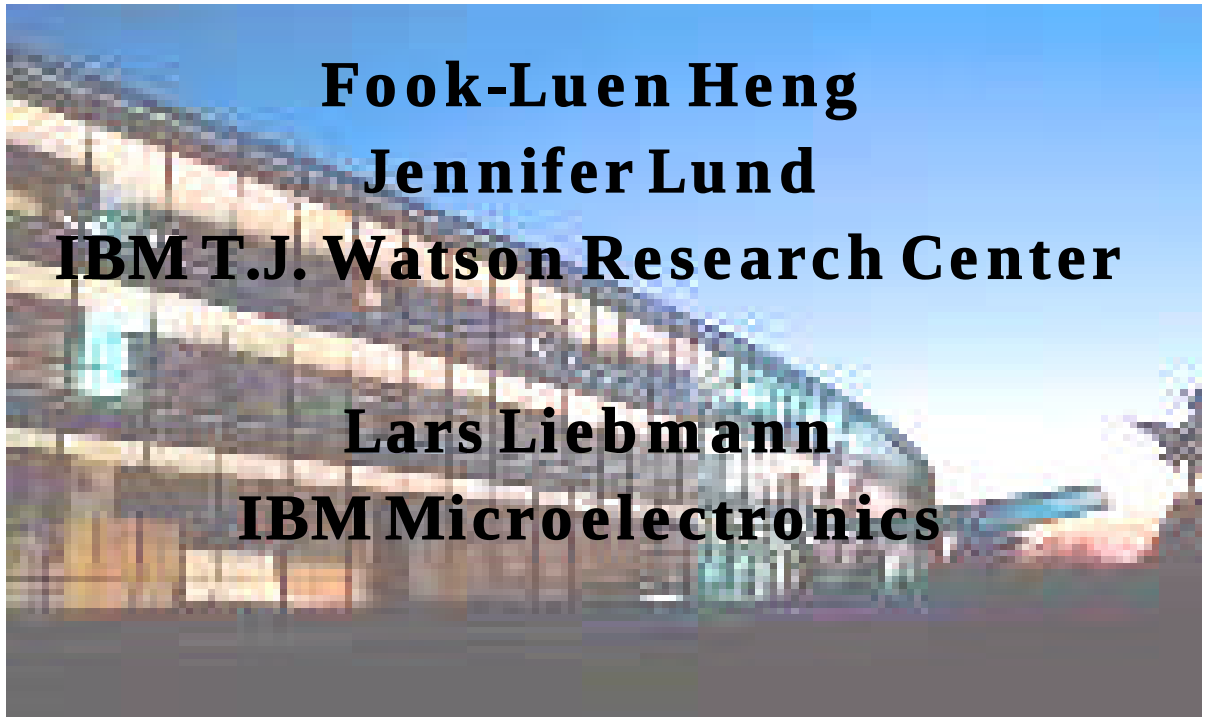
Application of Automated Design Migration to Alternating Phase Shift Mask (AltPSM) Design



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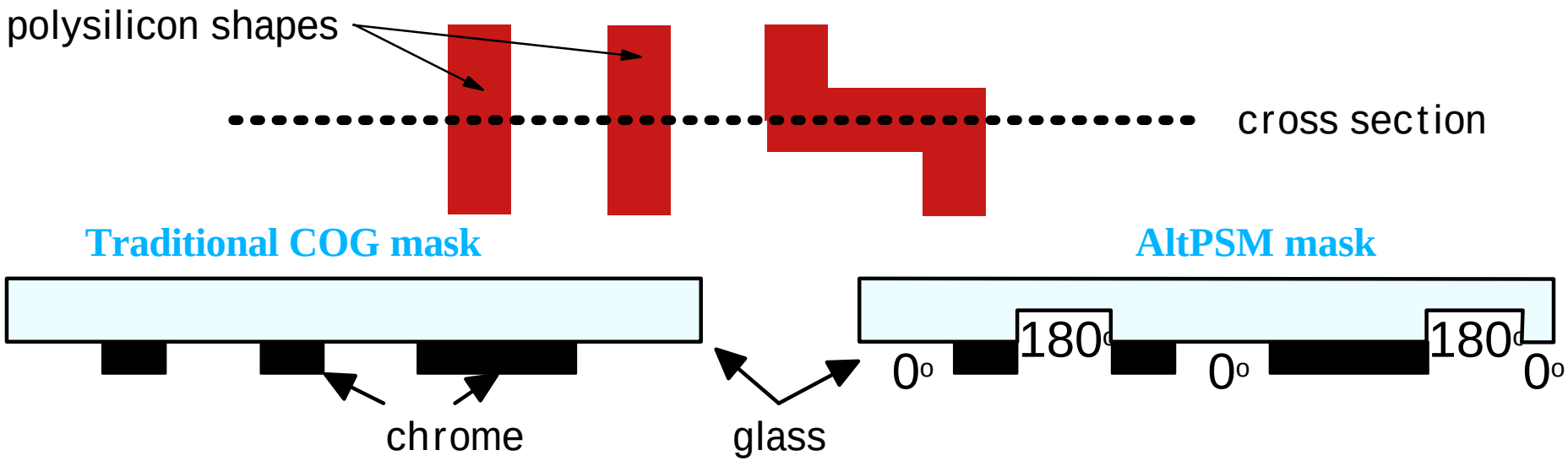
Outline

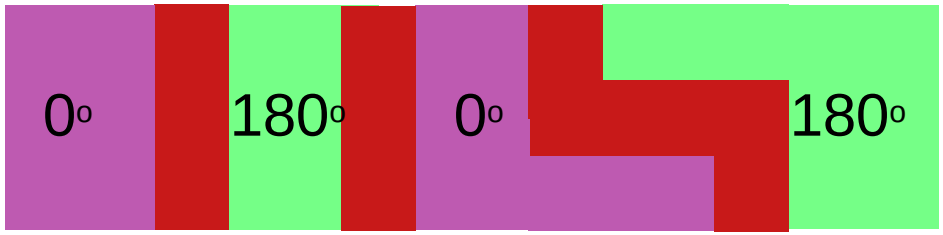
- Background
- Prior art in altPSM legalization
- Our approach
- Results
- Future challenges

AltPSM Primer

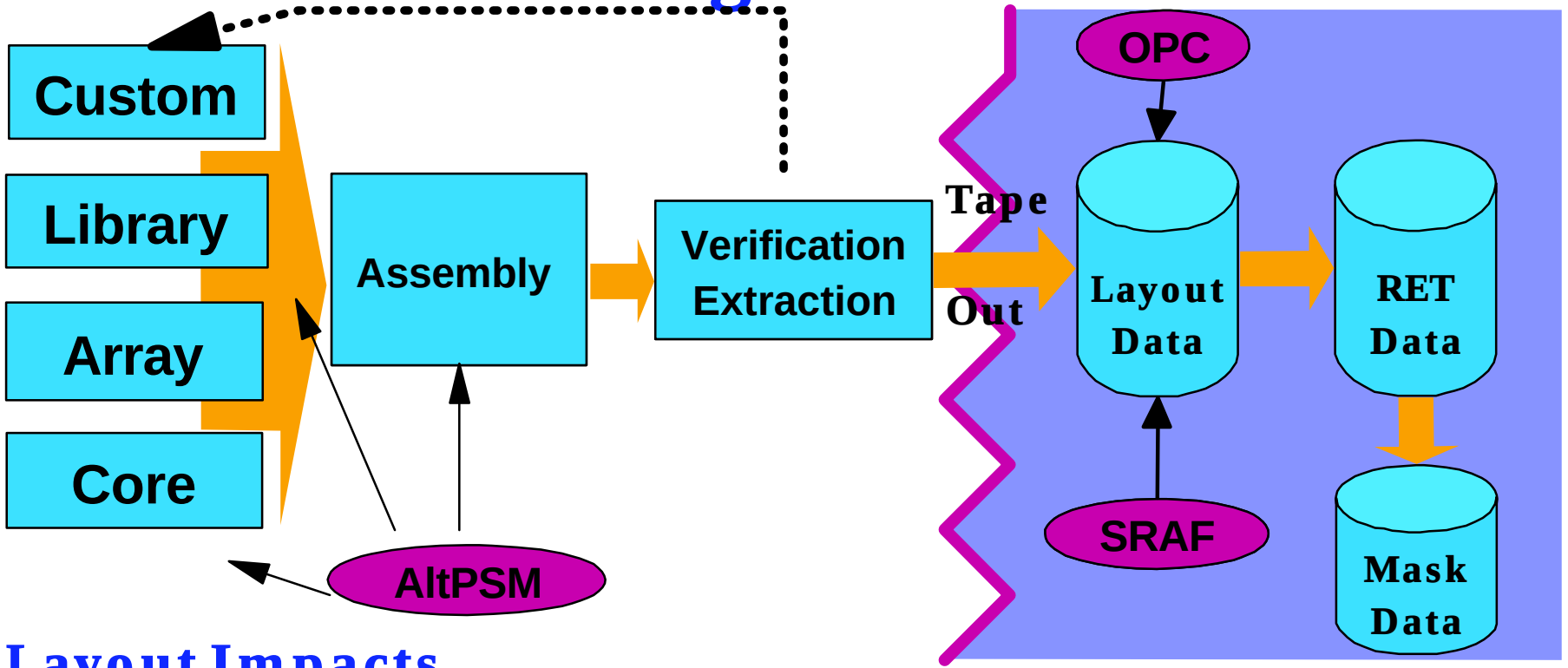
- **Powerful Resolution Enhancement Technique (RET)**
- **Uses destructive interference of projecting light**



- **Phase shapes need to be created for critical elements**
- **They need to satisfy the phase transition requirement**



Background

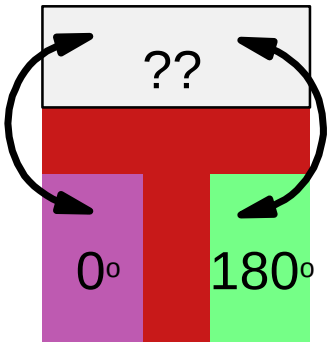


Layout Impacts

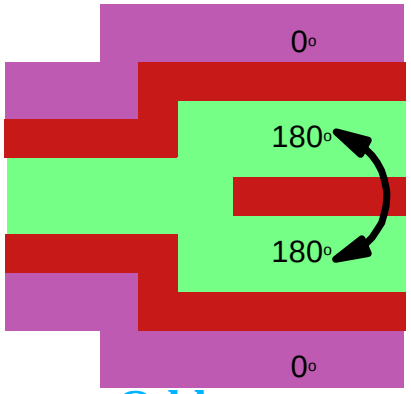
- Density impacts: up to 6% (180nm node)
- Resource impacts: 10-20%
  - Verification, phase shapes generation
  - AltPSM legalization and migration
  - Assembly methodologies

Conflicts in AltPSM Layouts

- **Forbidden Topologies**

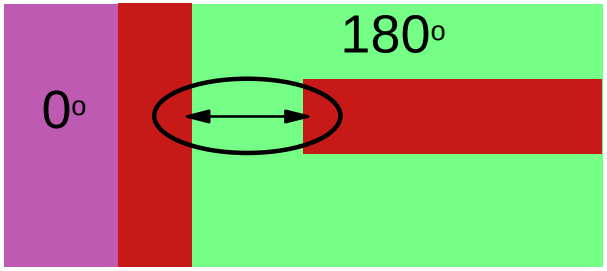


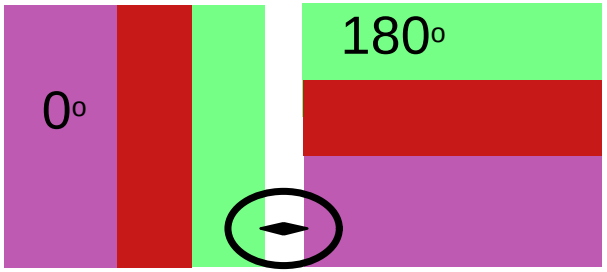
T-junction



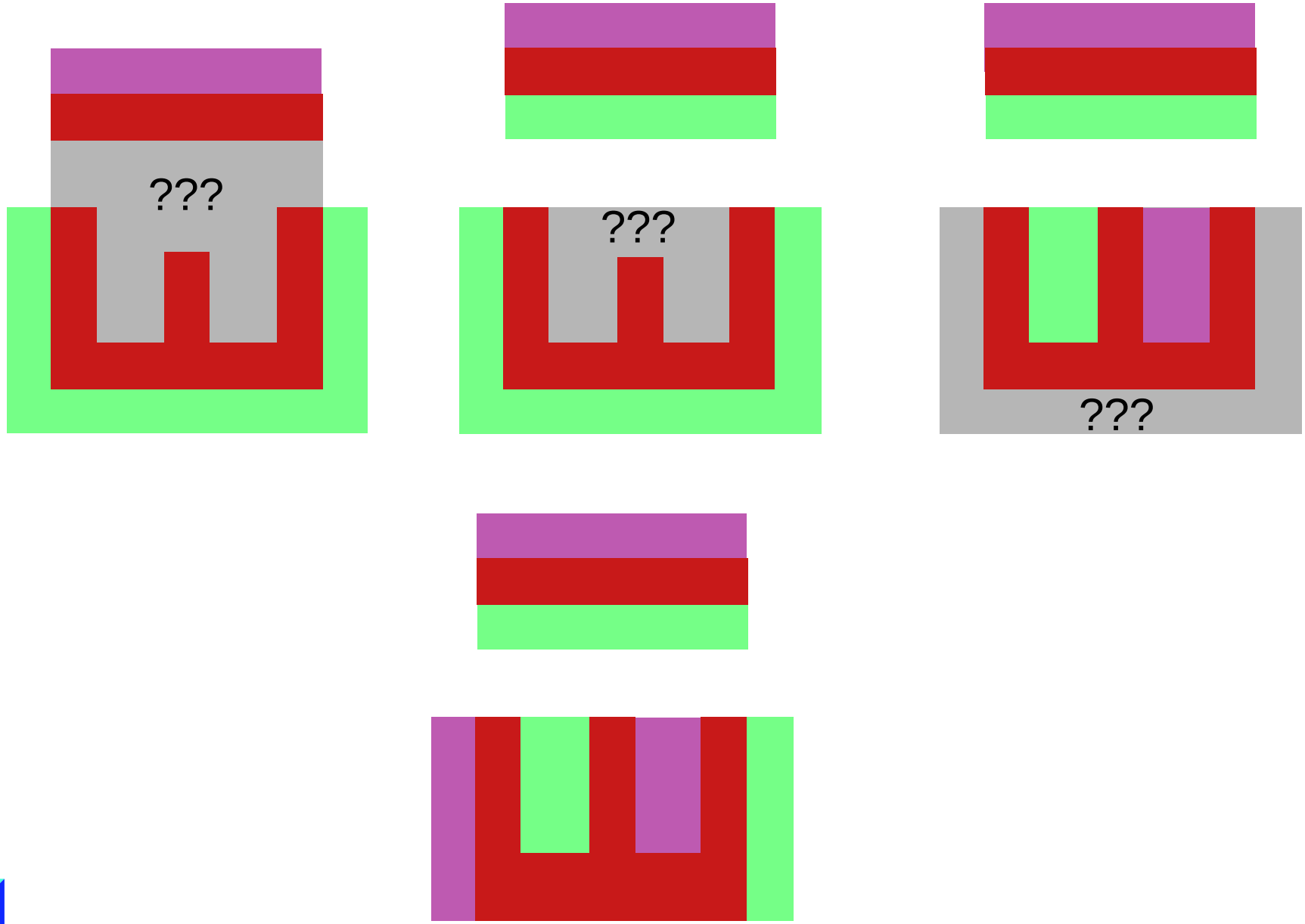
Odd-even run

- **Spacing conflict**





Resolving AltPSM Conflicts



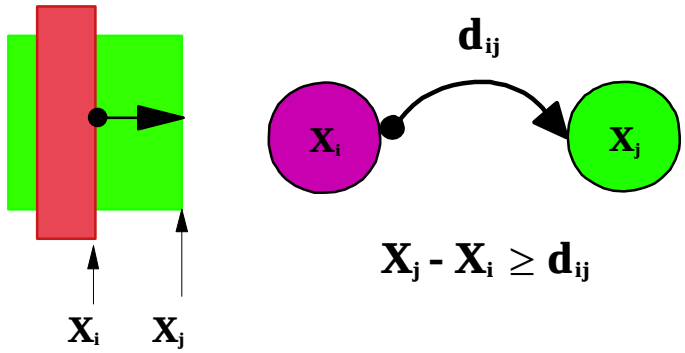
Prior Art in Layout Legalization

Compaction

- Legalizes a layout topology

  Minimize: $\Sigma\, x_i$

  Subject to: $x_i - x_j \geq d_{ij}$



- Translate symbolic layout to physical layout

Mimimum Perturbation

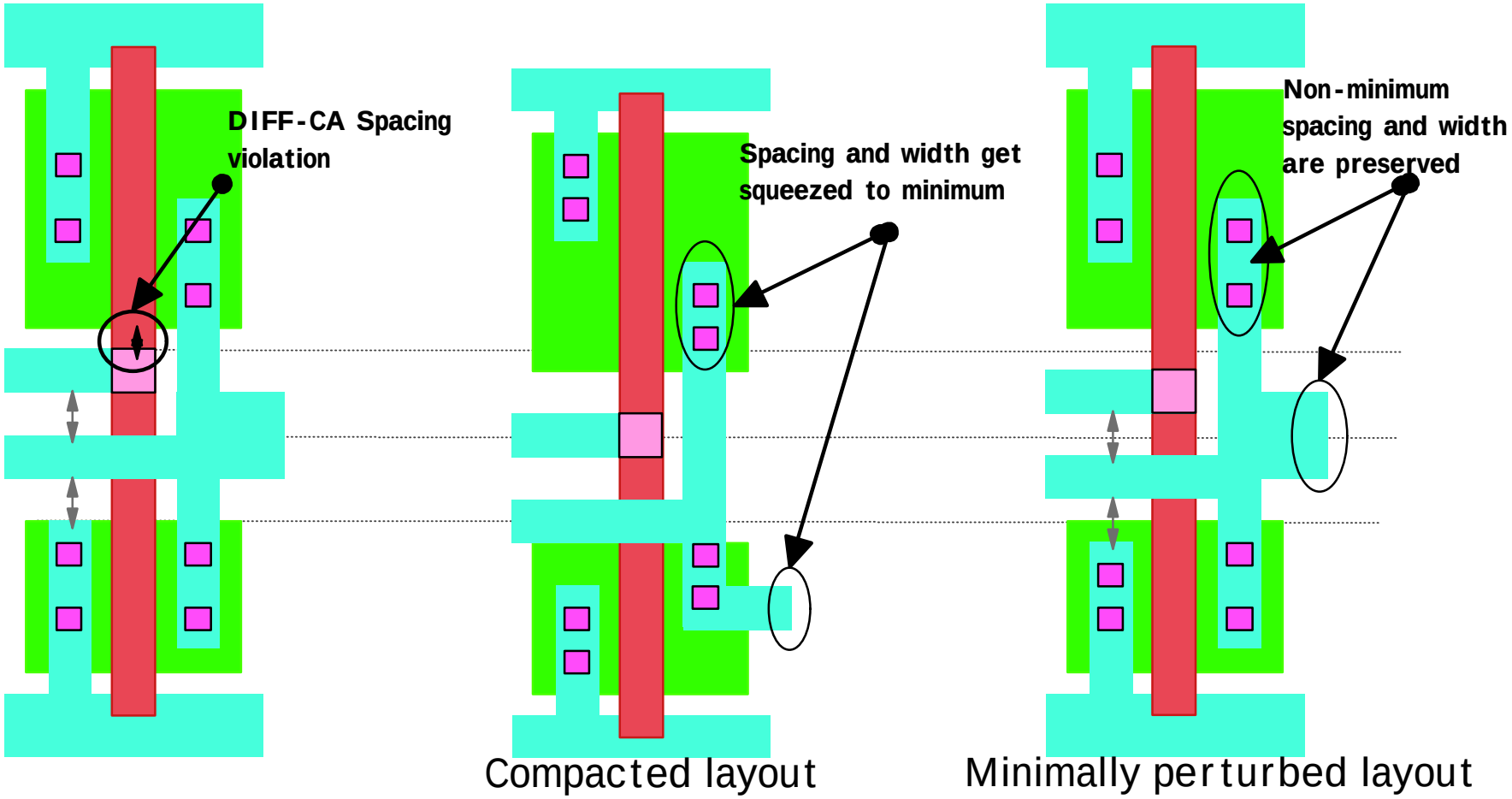
- Legalizes an almost correct layout

  Minimize: $w_i \bullet \| x_i - x_i^{old} \|$

  Subject to: $x_i - x_j \geq d_{ij}$

- Migrate existing layouts from source to target technology

Prior Art in Layout Legalization

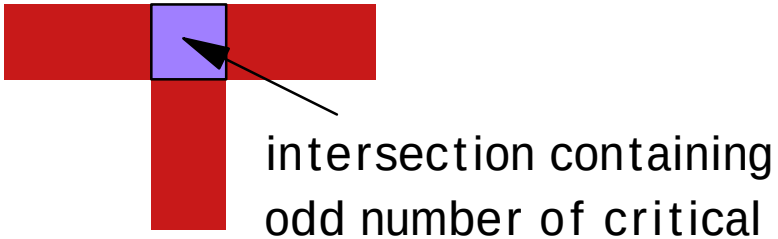


- Constraint based
- Adjacent relationship between objects does not capture altPSM requirements

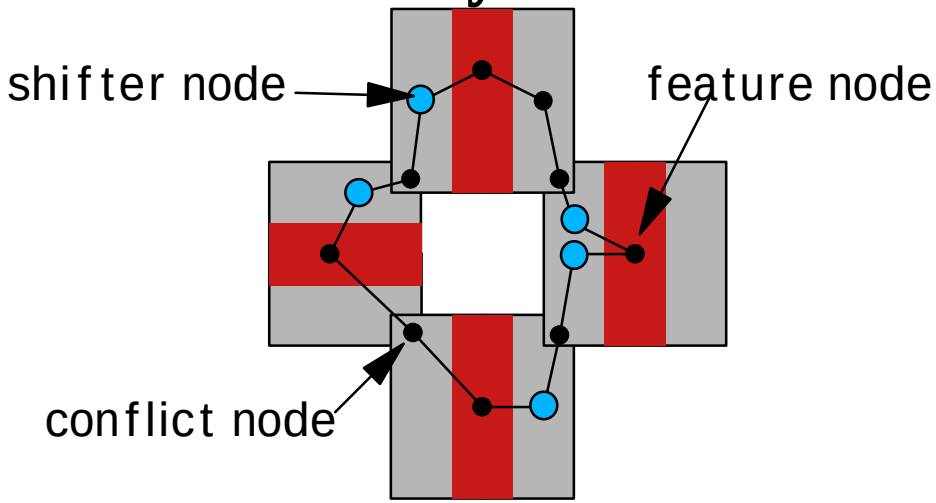
Conflict Detection & Legalization

PSM Verification (Galan et al)

- Geometric method based on counting ends
- Legalization based on design guidelines
- Exceptions are allowed in waivered layouts



Geometric method



Feature graph

Graph Bipartizations (Kahng et al)

- Graph theoretic method using a *feature graph*
- Legalization formulated as a graph bipartization
- Minimum topological modification

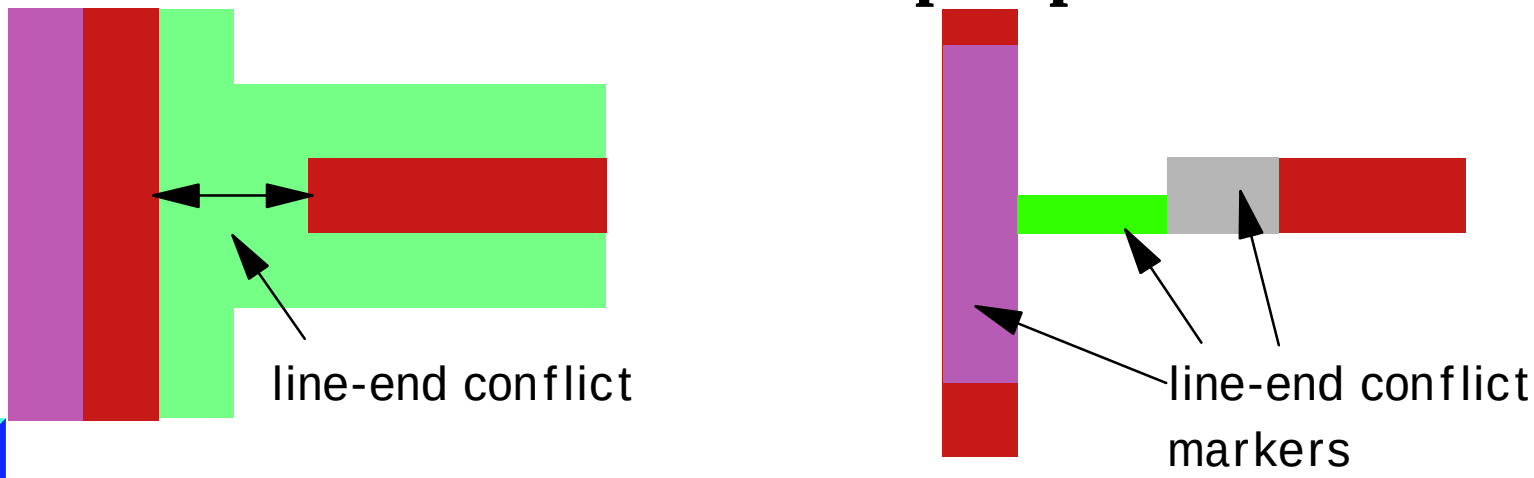
Marker Shapes

- Derived shapes that denote conflicts
- Used to suggest legal solutions

Marker shapes generation

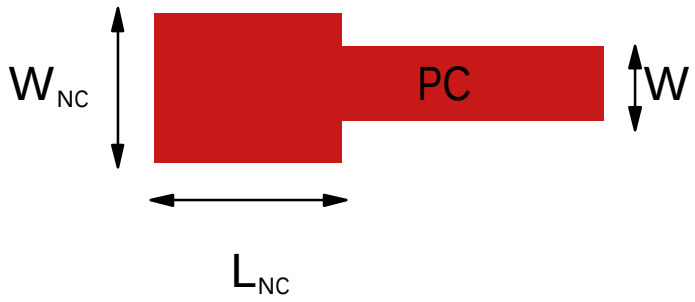
1. Classified critical features

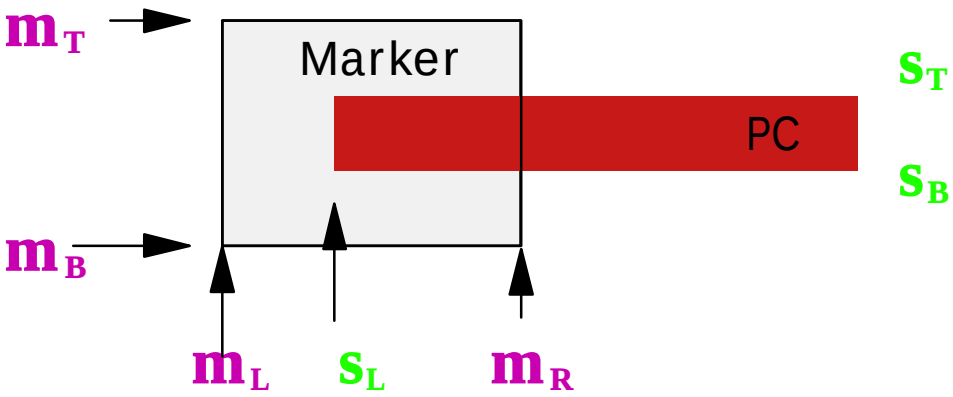
2. DRC - including altPSM conflict detection
3. Derived markers with shape operations



Instructing Minimum Perturbation

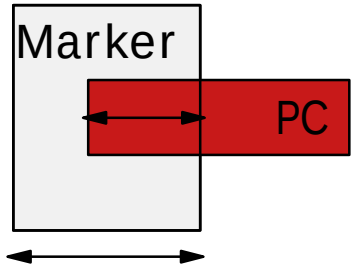
- W_{NC} : Non-critical width
- L_{NC} : Non-critical length
- W : Width of PC shape





- Edges of marker coincident with PC shape
- m_L, m_R, m_T, m_B denote left, right, top and bottom edges of marker
- s_L, s_T, s_B denote left, top and bottom edges of PC

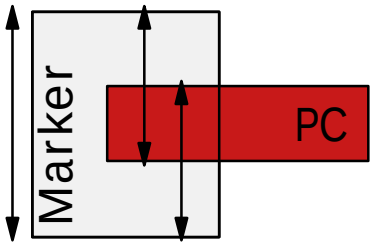
Instructing Minimum Perturbation



X-direction rules

- **Intersection(Marker, PC) $\geq L_{NC}$**
- **Length(Marker) $\geq L_{NC}$**

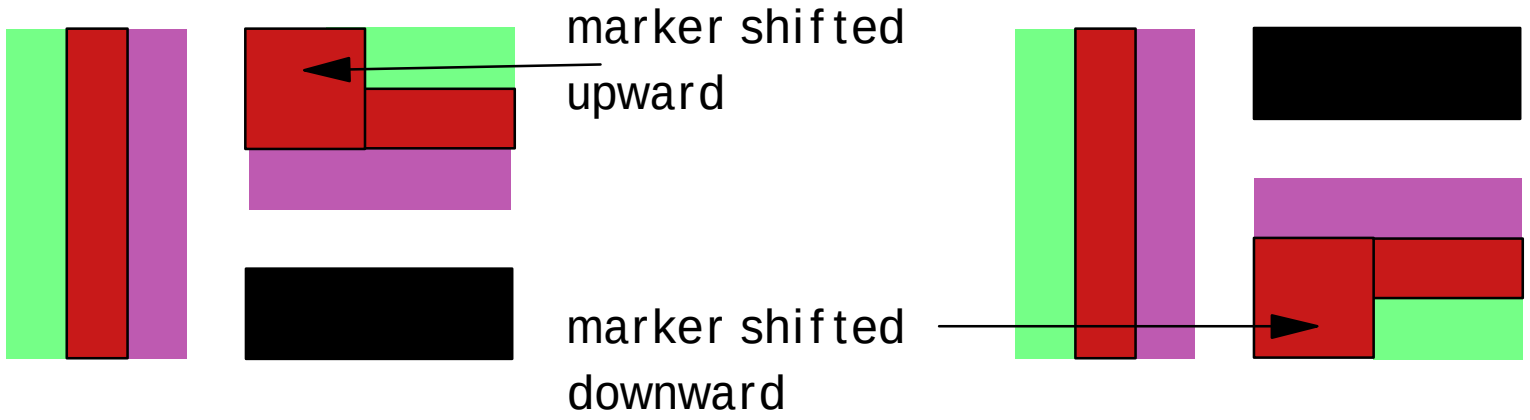
$$m_R - s_L \geq L_{NC}$$
$$m_R - m_L \geq L_{NC}$$



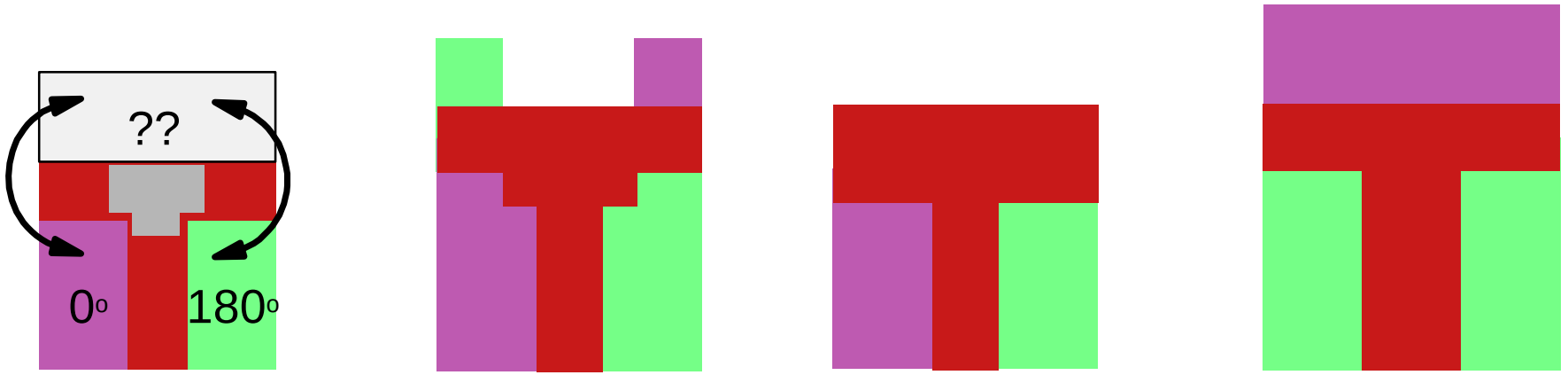
Y-direction rules

- **OverlapOf(Marker, PC) $\geq W$**
- **Width(Marker) $\geq W_{NC}$**

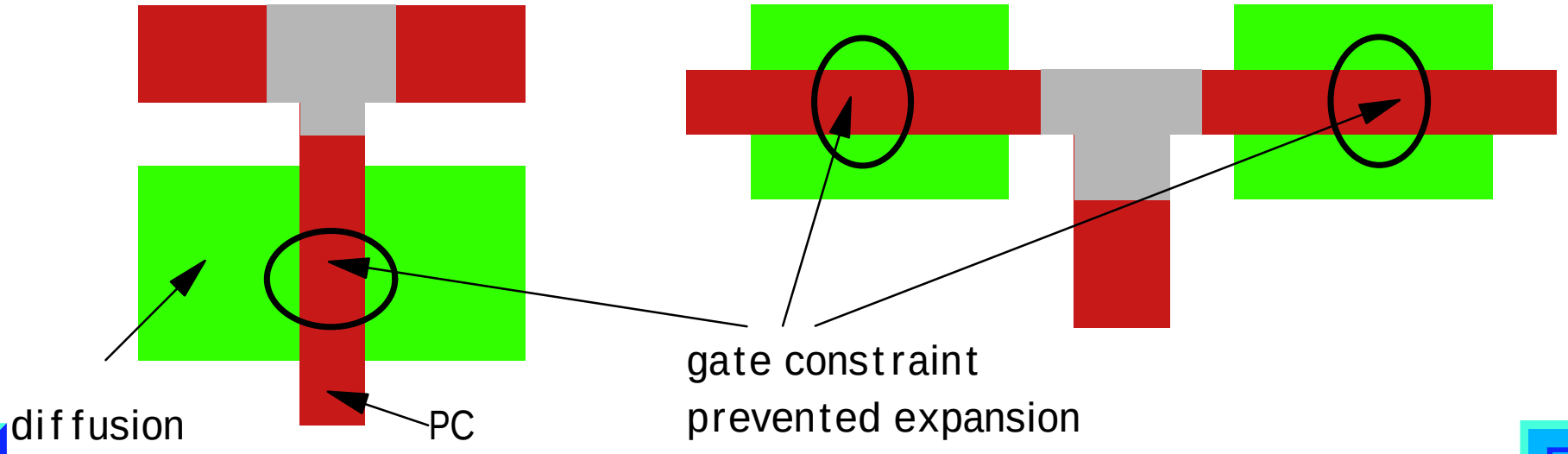
$$m_T - s_B \geq W$$
$$s_T - m_B \geq W$$
$$m_T - m_B \geq W_{NC}$$



Resolving T-junction Conflict



- **In practice, use a simplified rule to expand all legs of T-junction**



Prioritization of Conflict Resolutions

- Adjust minimum perturbation objective function
- Manipulate layout variables to control changes

1. Expand marker shapes
   - ➡ Freeze non-marker variables
2. Move and/or expand marker shapes and critical features without size increase
   - ➡ Un-freeze variables of critical features
   - ➡ Add source to sink upper bound constraint
3. Allow shapes in predetermined level to move
   - ➡ Un-freeze variables of shapes
4. Allow layout to expand by percentage
   - ➡ Expand upper bound constraint

Summary

Summary

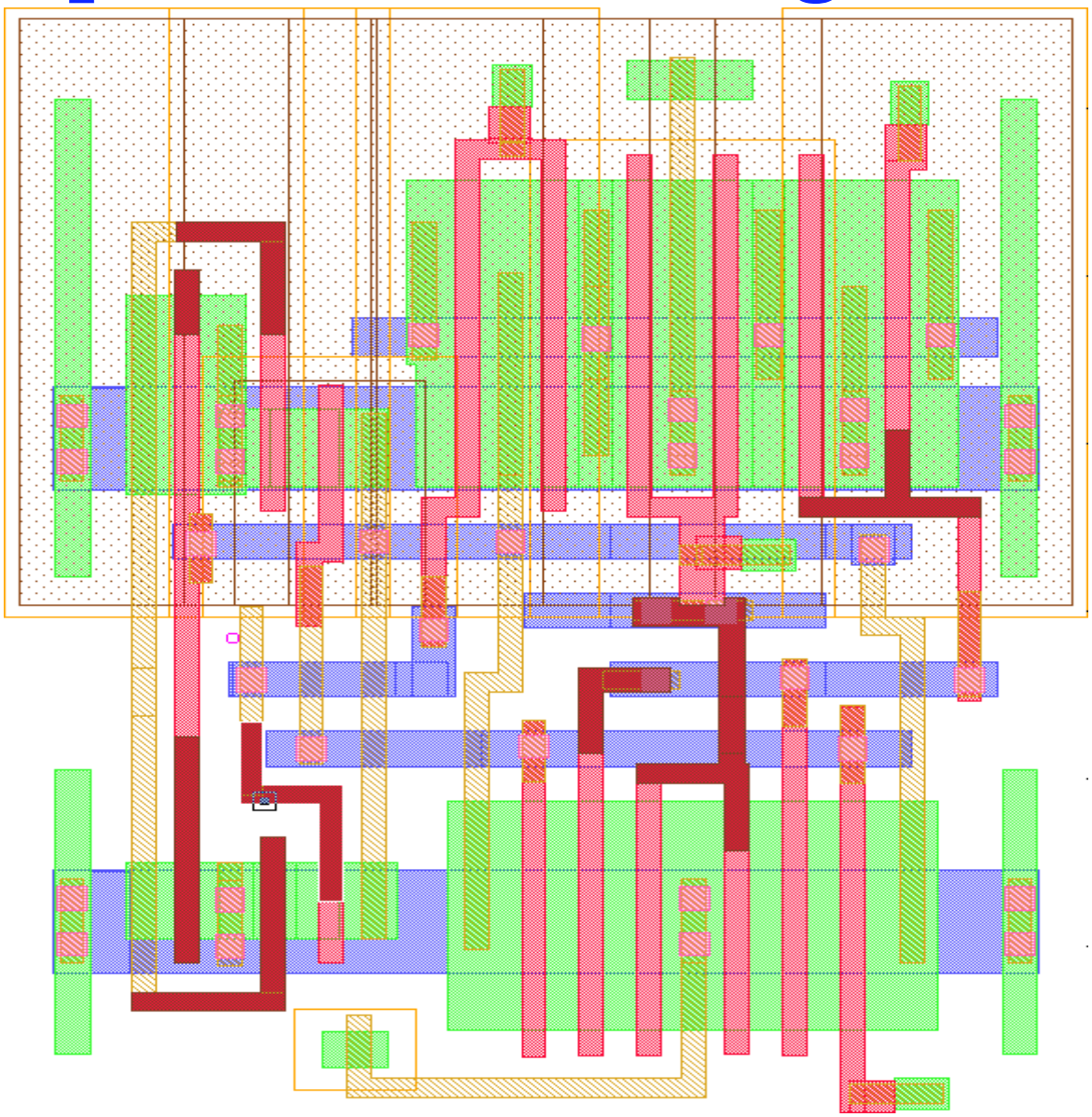
- AltPSM legalization is more an art than a science
- Used marker shapes to indicate conflicts
- Designed solutions based on experience
- Formulated sol'n as a layout optimization problem
- Prioritized solutions based on design preferences

Results

Results

- Customized MASH to perform altPSM legalization
- Migrated layouts comparable with manual results
- Typical standard cell took between 1 and 30 secs
- A custom multiplexer with 50+ devices took < 1 min
- Same layout took 8 hrs to legalize manually !
- Established a feasibility milestone

Example of AltPSM Legalization



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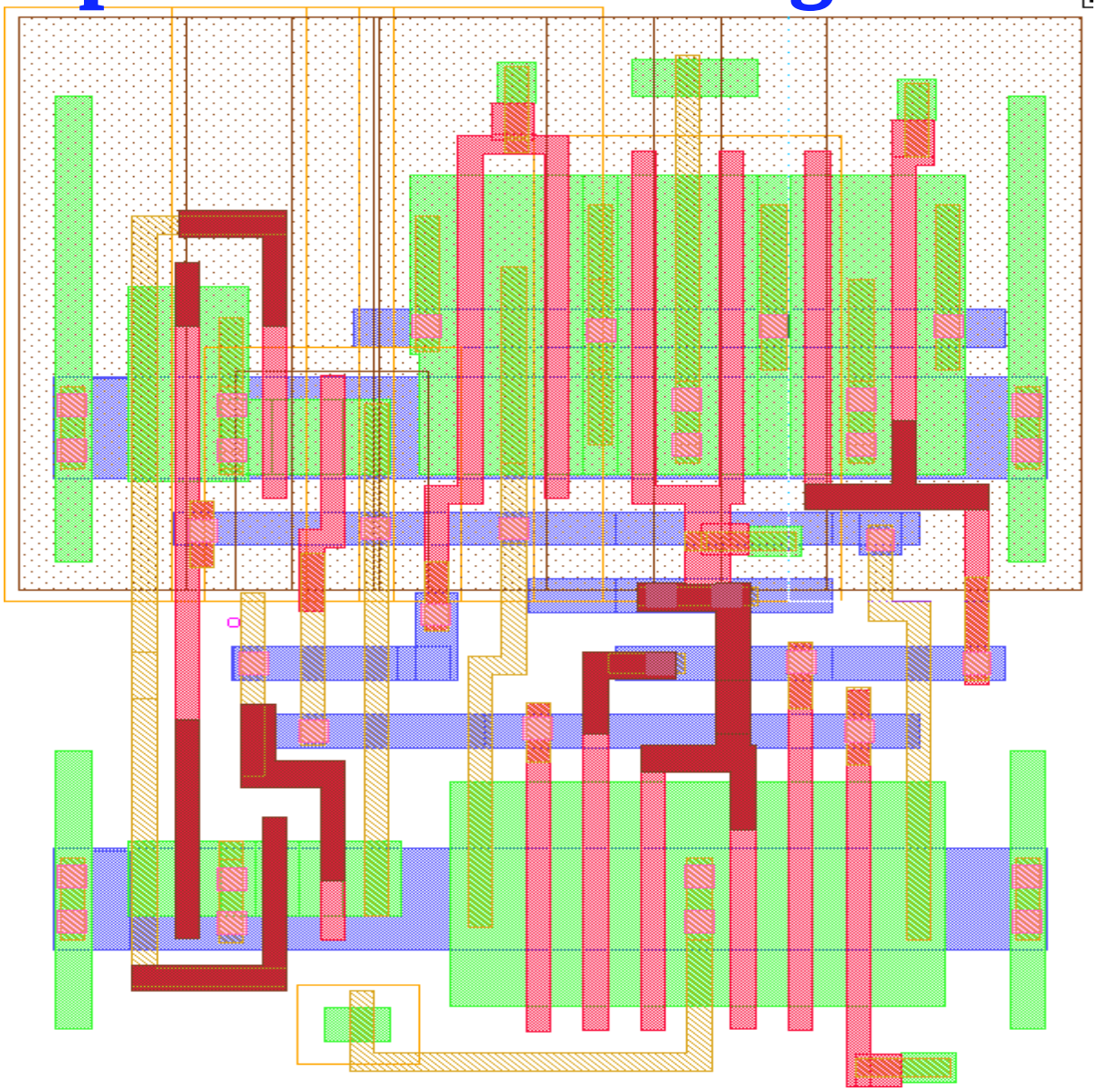
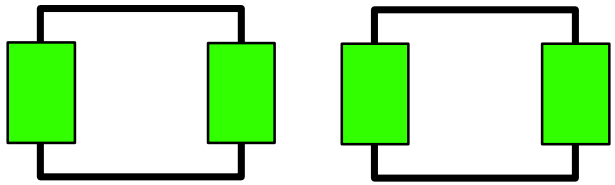
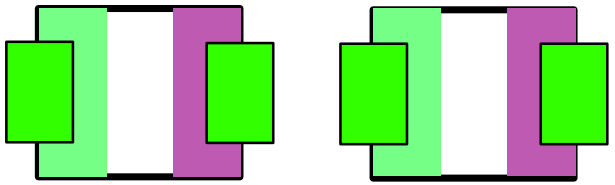


Future Challenges

- Constraint generation technique that discovers altPSM requirements
- Automation to create altPSM compliant layouts
- AltPSM assembly tools and methodologies



Today's standard cells



Cells with phase shapes