UFO: Unified Convex Optimization Algorithms for Fixed-Outline Floorplanning

Speaker: Jai-Ming Lin

Department of Electrical Engineering,
National Cheng Kung University,
Tainan, Taiwan, R.O.C

Outline

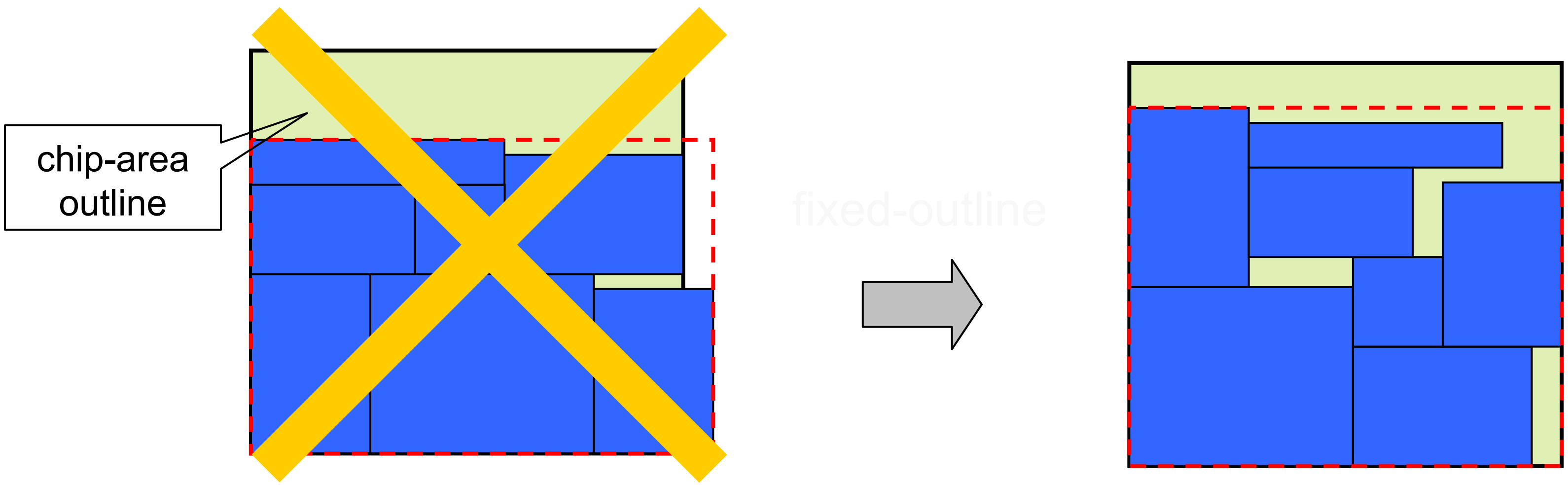
I. Introduction
II. Problem Formulation
III. Global Distribution
IV. Local Legalization
V. Experimental Results
VI. Conclusions

I. Introduction

- **Importance of fixed-outline floorplanning**

  (1) Kahng (*ISPD* 2000): a floorplan with pure area minimization may be useless since it may be fail to fill into the given region

  (2) Adya and Markov (*ICCD* 2001): floorplanning with the fixed-outline constraint is considered much more difficult than the outline-free floorplanning.



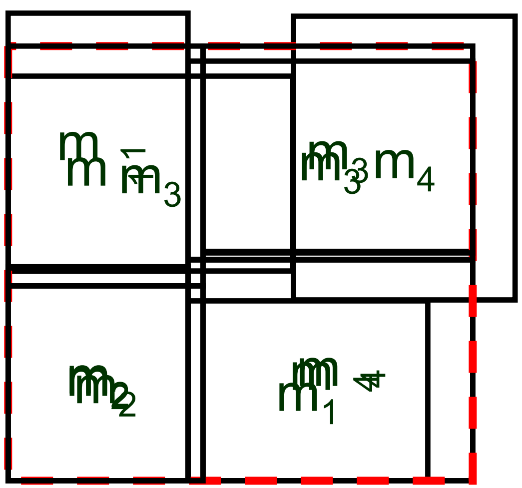
I. Introduction

- **Fixed-outline floorplanning**

  (1) Give a set of modules and an actual chip outline

  (2) Determine the geometrical relations of modules to place them into the outline so that wirelength is minimized

  (3) Change the shapes of modules to further optimize the result



I. Introduction

- The methodology used in floorplanning can be classified into two types as follows:

  (1) Representation based approach
  (2) Analytical mathematical approach

- Analytical based approach has the following advantages comparing to representation based approach:

  (1) Modules are not compacted to the bottom-left side.
  (2) It is more easy to deal with the pre-placed constraint.

I. Introduction

- Although our method looks similar to the method proposed by Luo et al.[19], they are different in the properties listed as follows:

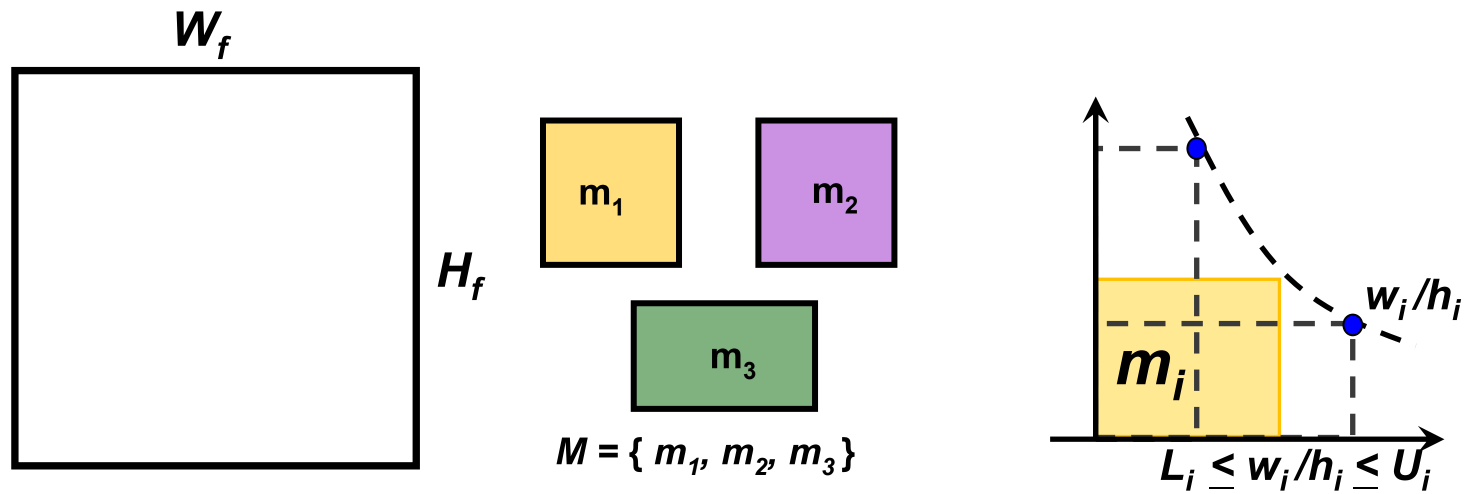
		UFO	Luo et al. [19]
first stage	model	**Pull-Push**	**A**ttractor-**R**epeller
	wirelength	actual length (d_{ij})	quadratic length (D_{ij})
	curve (see Fig. 7)	monotonic decreasing function + monotonic increasing function	constant value + monotonic increasing function
second stage	formaultion	quadratic optimization programming	second-order cone programming
	objective	fixed outline constraint	wirelength
	topology	constraint graphs	relative position matrix

Outline

II. Problem Formulation

(i) Input:

1. A fixed die whose width and height are W_f and H_f
2. A set of modules $M = \{m_1, m_2, \ldots, m_n\}$ and a netlist
3. For each m_i, its width and height are w_i and h_i. Its aspect ratio (i.e., w_i/h_i) is bounded in the range $[L_i, U_i]$ under a fixed area A_i.



(ii) Output:

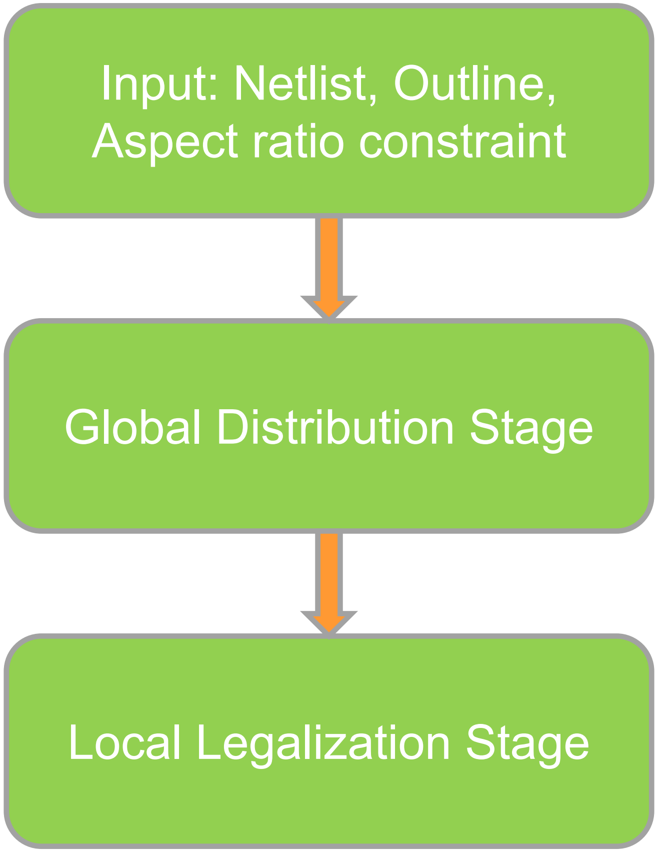
The set of modules are placed in the outline with no modules overlap and the **total wirelength** is minimized.

Outline

I. Introduction
II. Problem Formulation
III. Global Distribution
IV. Local Legalization
V. Experimental Results
VI. Conclusions

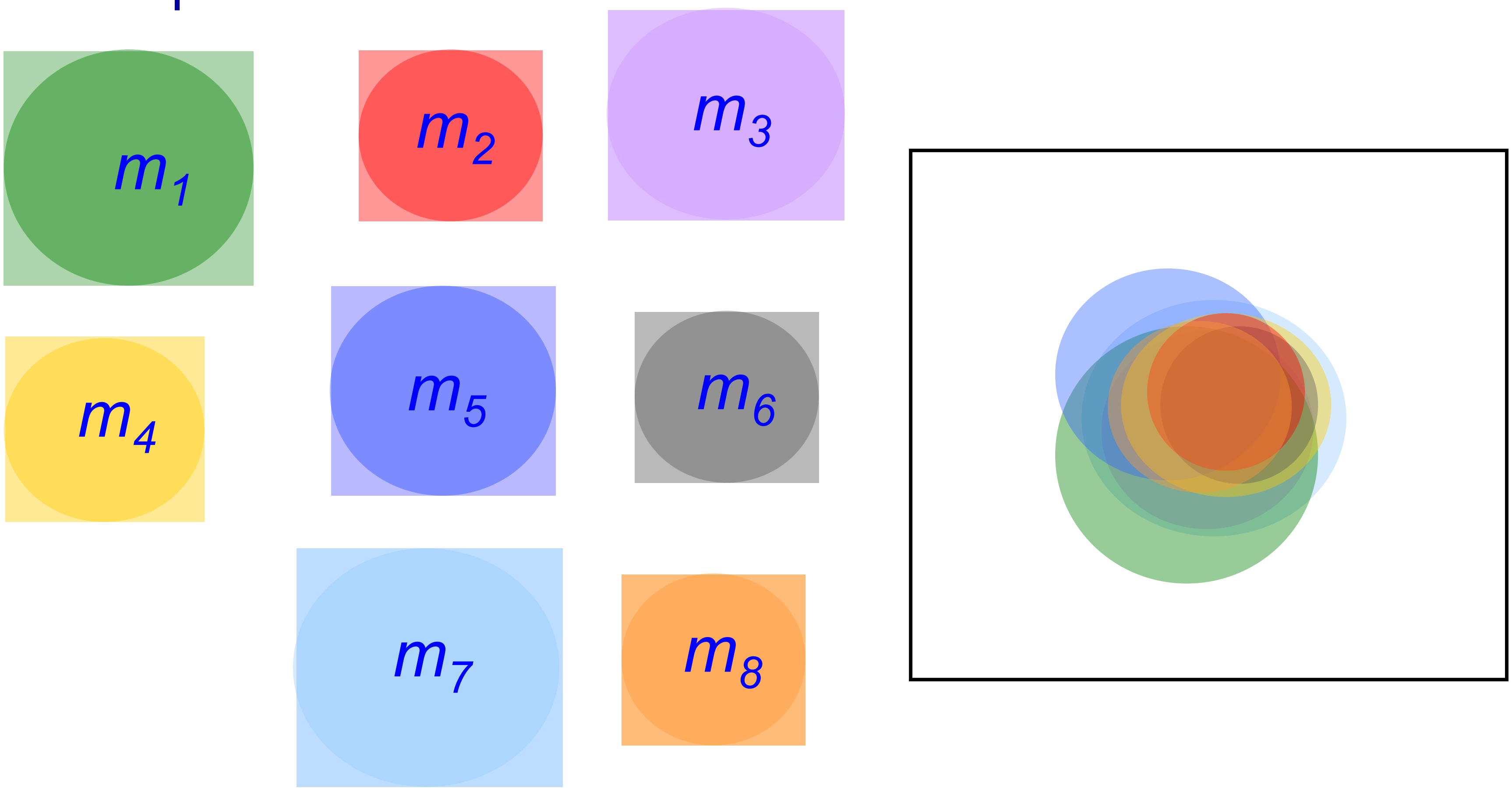
III. Global Distribution

- **Two stages of UFO**
  (1) Global distribution stage
  (2) Local legalization stage



III. Global Distribution

Purpose: uniformly distribute modules over a fixed-outline such that the total wirelength can be minimized with slight overlap between modules

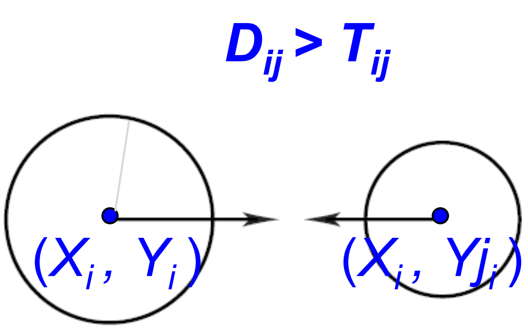


III. Global Distribution

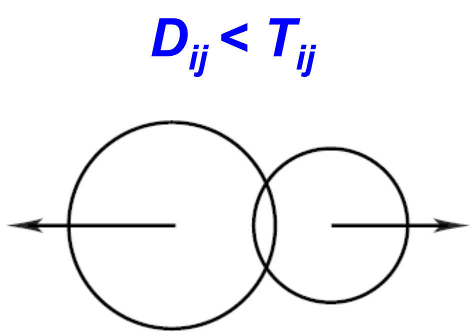
- **Attractor-Repeller (AR) Model by Luo et. al.**: piecewise function F_{ij} for two circles C_i and C_j:

$$F_{ij}\left(x_i,x_j,y_i,y_j\right) := \begin{cases} c_{ij}D_{ij} + \dfrac{t_{ij}}{D_{ij}} - 1, & D_{ij} \geq T_{ij} \\ 2\sqrt{c_{ij}t_{ij}} - 1, & 0 \leq D_{ij} < T_{ij} \end{cases}$$

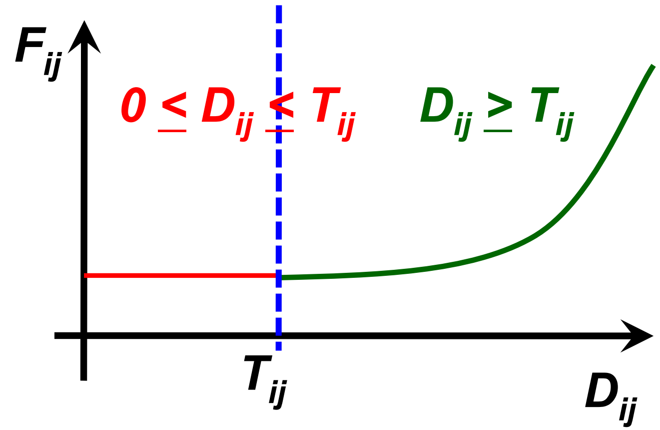
- c_{ij}: connectivity of two circles C_i and C_j
- $D_{ij} = (X_i - X_j)^2 + (Y_i - Y_j)^2$
- $t_{ij} = \sigma(r_i + r_j)^2$, $\sigma > 0$
- $T_{ij} = \sqrt{\dfrac{t_{ij}}{c_{ij} + \varepsilon}}$, $\varepsilon > 0$



Attractive force

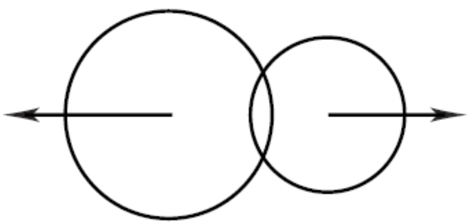


Repulsive force



III. Global Distribution

- Deficiencies of **A**ttractor-**R**epeller (**AR**) Model:
  - (1) Repeller force is weak.
  - (2) Results depend on the user specified parameters.



Repulsive force

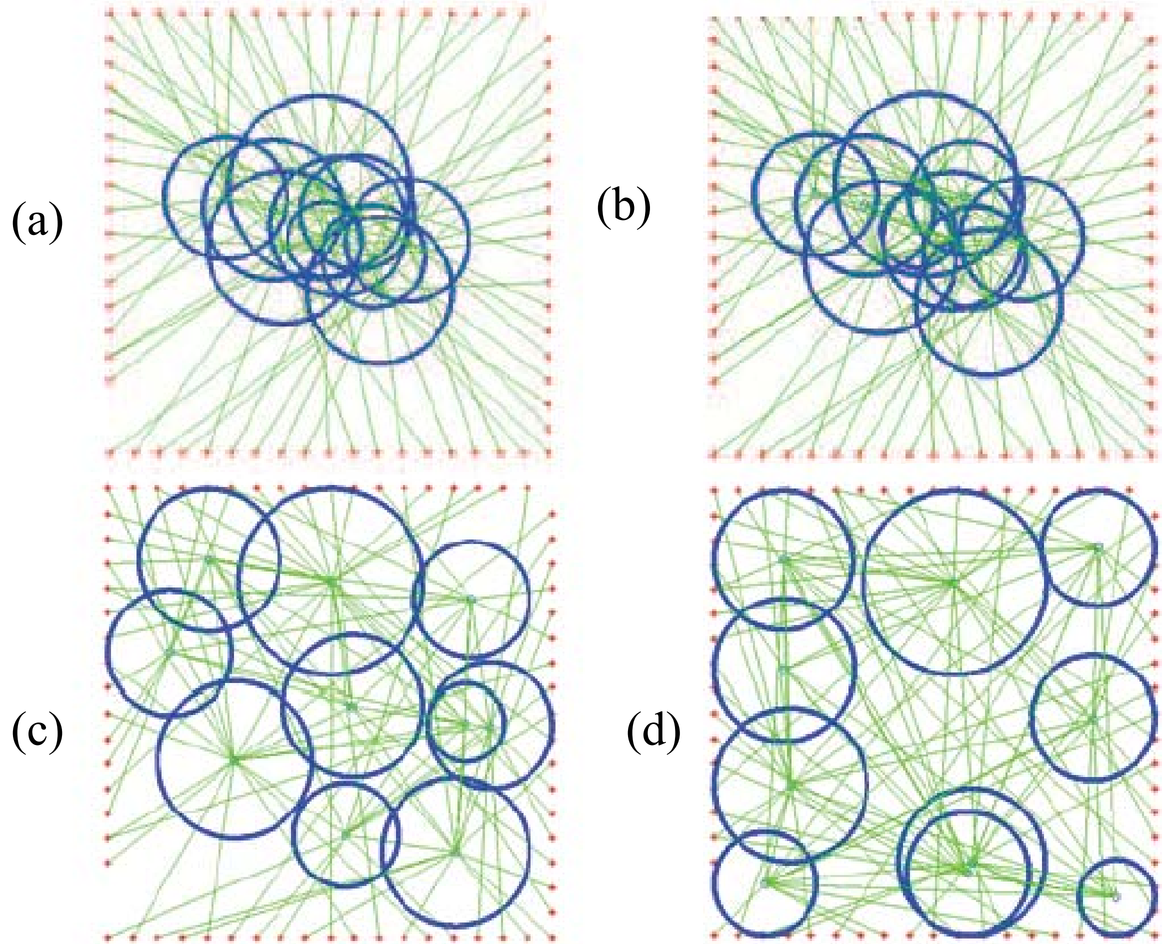
$$c_{ij}D_{ij} + K\left(\frac{t_{ij}}{D_{ij}} - 1\right)$$

(a) K = 10^0

(b) K = 10^3

(c) K = 10^5

(d) K = 10^7

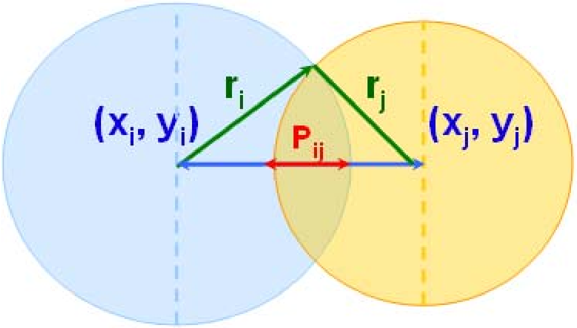


III. Global Distribution

- **P**ull-**P**ush (**PP**) Model:

$$f_{ij}(X_i, X_j, Y_i, Y_j) = \begin{cases} c_{ij}\, d_{ij} + s_{ij}\dfrac{p_{ij}}{d_{ij}}, & p_{ij} \geq 0 \\ c_{ij}\, d_{ij} + \dfrac{p_{ij}}{d_{ij}}, & p_{ij} < 0 \end{cases}$$

- s_{ij}: A_i X A_j
- $d_{ij} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$
- p_{ij}: $(r_i + r_j) - d_{ij}$



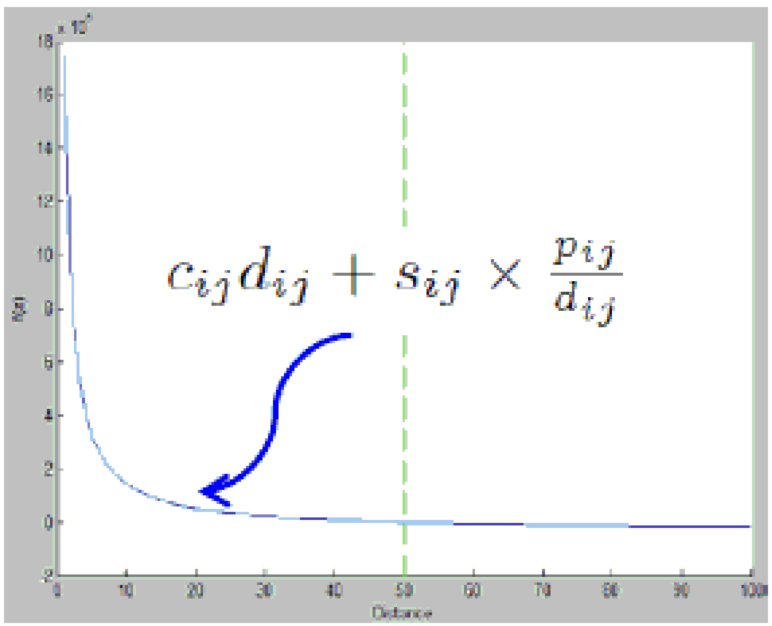
(1) Consists of two equations which represent two circles overlap ($p_{ij} \geq 0$) and separate ($p_{ij} < 0$).
(2) Uses d_{ij} instead of D_{ij} .
(3) Gives a large push force (proportional to the size of two modules) while they overlap.
(4) Gives a stable push force if two circles separate.

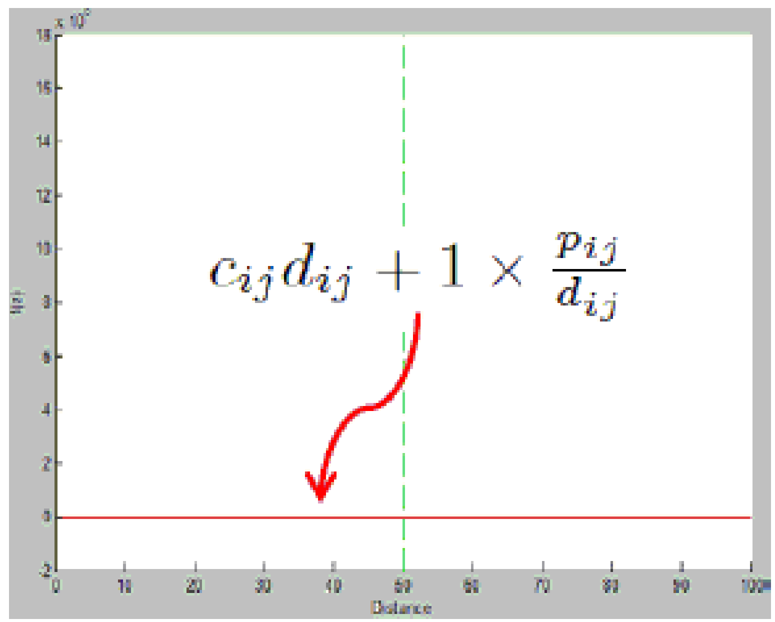
III. Global Distribution

- **Pull-Push (PP) Model:**

$$f_{ij}(X_i, X_j, Y_i, Y_j) = \begin{cases} c_{ij}\, d_{ij} + s_{ij}\dfrac{p_{ij}}{d_{ij}}, & p_{ij} \geq 0 \\ c_{ij}\, d_{ij} + \dfrac{p_{ij}}{d_{ij}}, & p_{ij} < 0 \end{cases}$$

- s_{ij}: A_i X A_j
- $d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$
- p_{ij}: $(r_i + r_j) - d_{ij}$,$_j$





III. Global Distribution

- **Mathematical formulation**:
  (1) Minimize the summation of function f_{ij} for each pair of circles C_i and C_j
  (2) Constrain all circles that are placed in the outline.

$$F = \min_{X_i, X_j, Y_i, Y_j} \sum_{1 \le i < j \le n} f_{ij}\left(X_i, X_j, Y_i, Y_j\right)$$

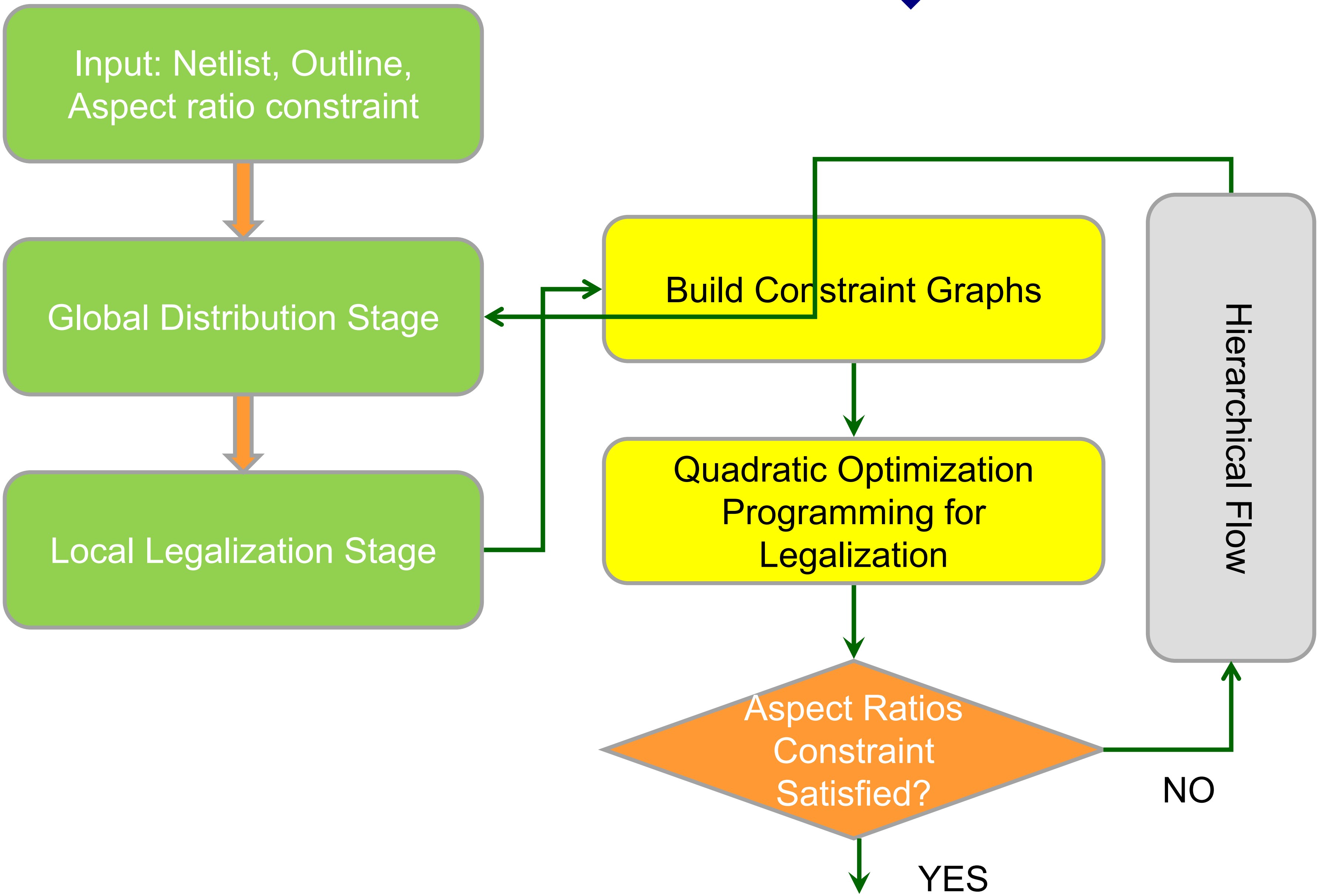
$$s.t.$$

$$X_i + r_i \le W_f, \qquad X_i - r_i \le 0,$$

$$Y_i + r_i \le H_f, \qquad Y_i - r_i \le 0,$$

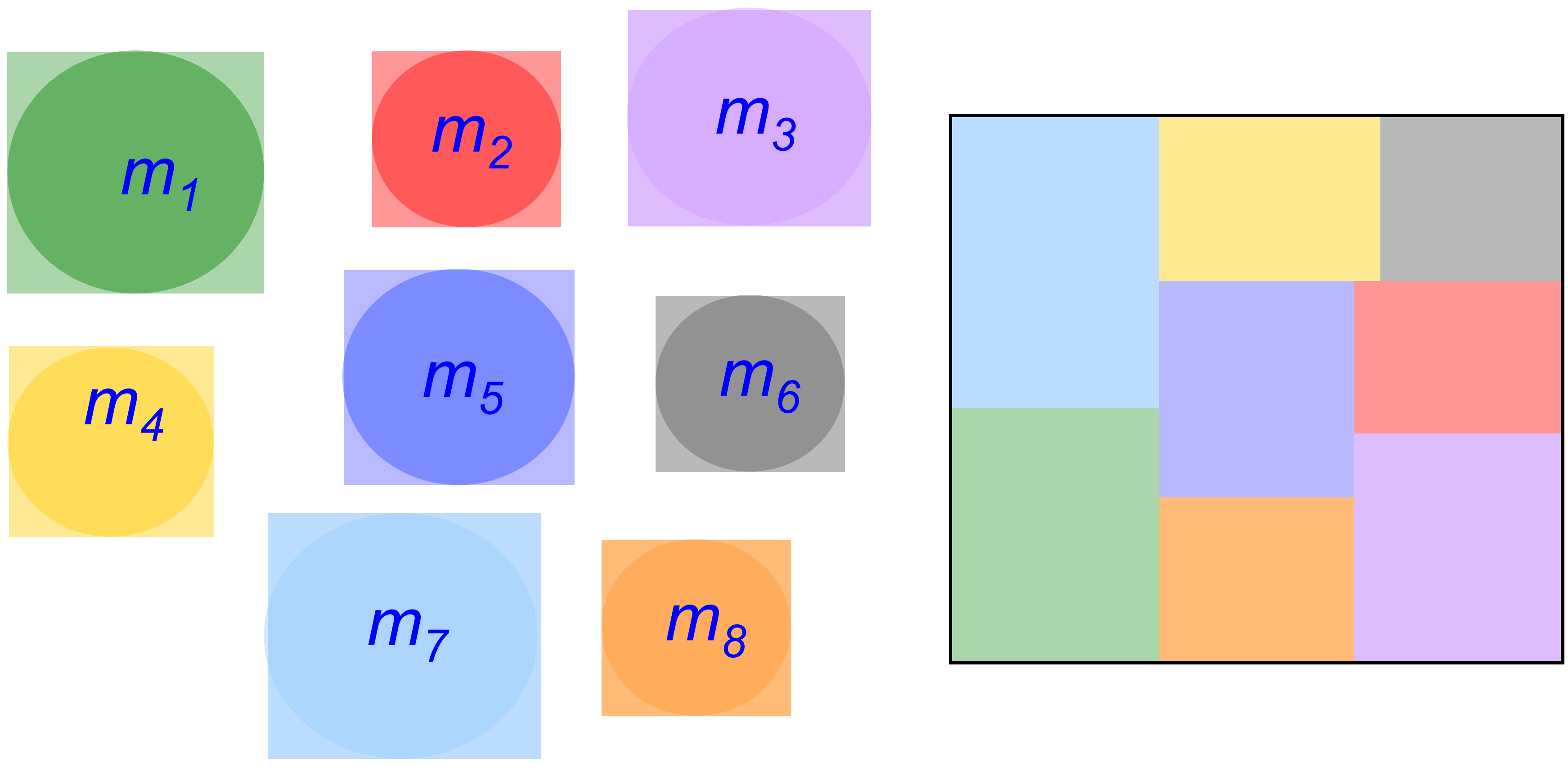
Outline

IV Flow in Local Legalization



IV. Local Legalization

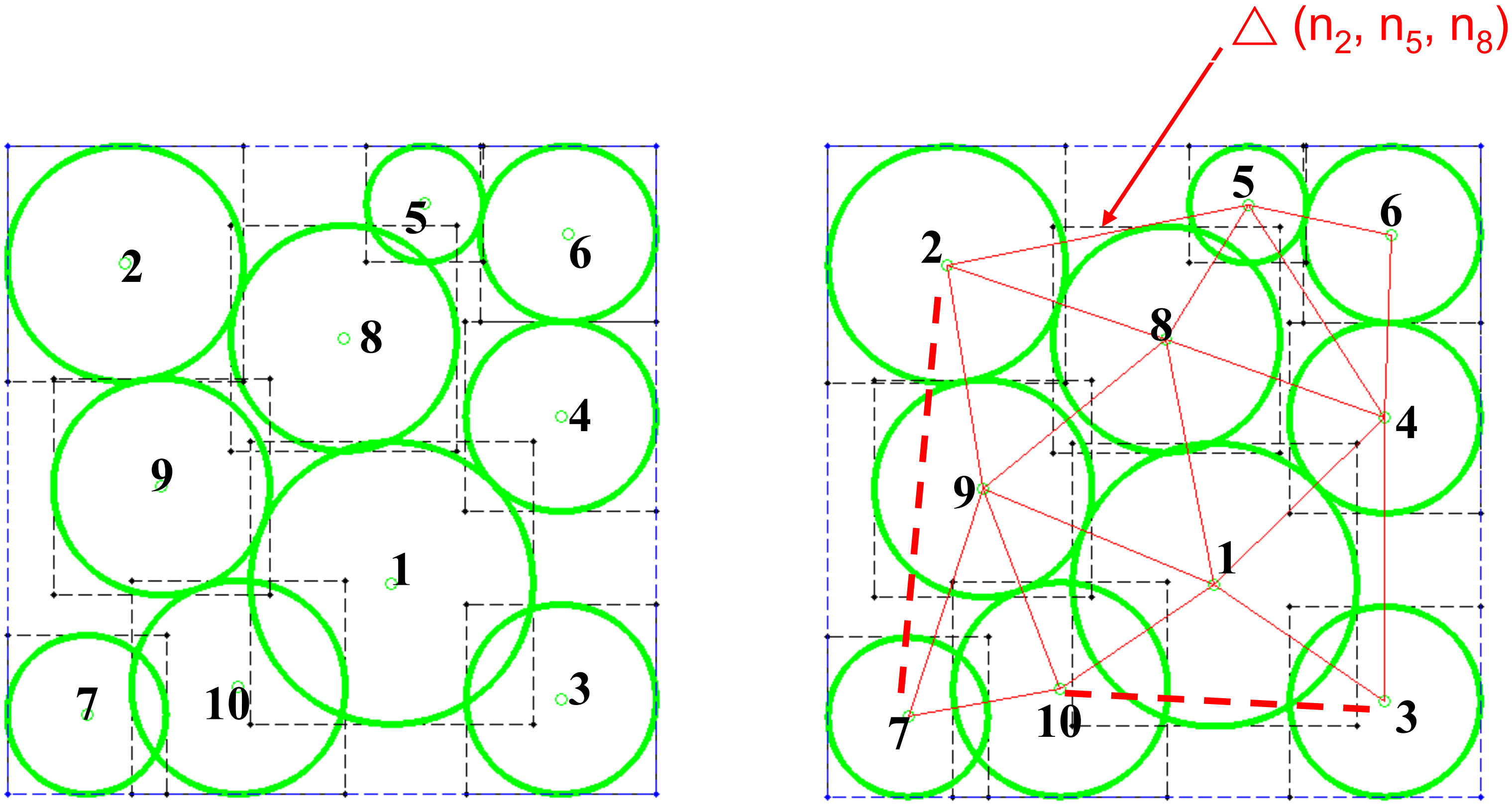
- **Purpose:** determine the shapes of modules so that no modules overlap.
  - Since we have obtained a good result, we hope to slight move for the results of global distribution stage.



IV. Local Legalization

(i) Constraint Graphs Construction

- Apply **D**elaunay **T**riangulation (**DT**) method to find neighboring modules m_i and m_j



(a) (b)

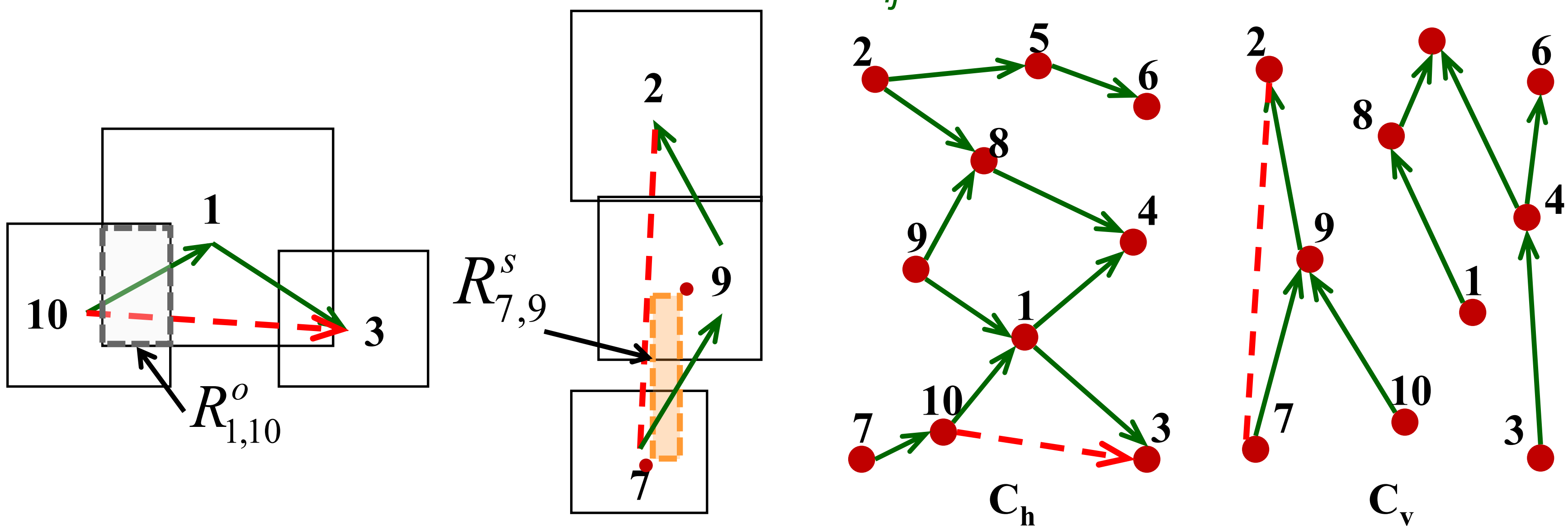
IV. Local Legalization

(i) Constraint Graphs Construction

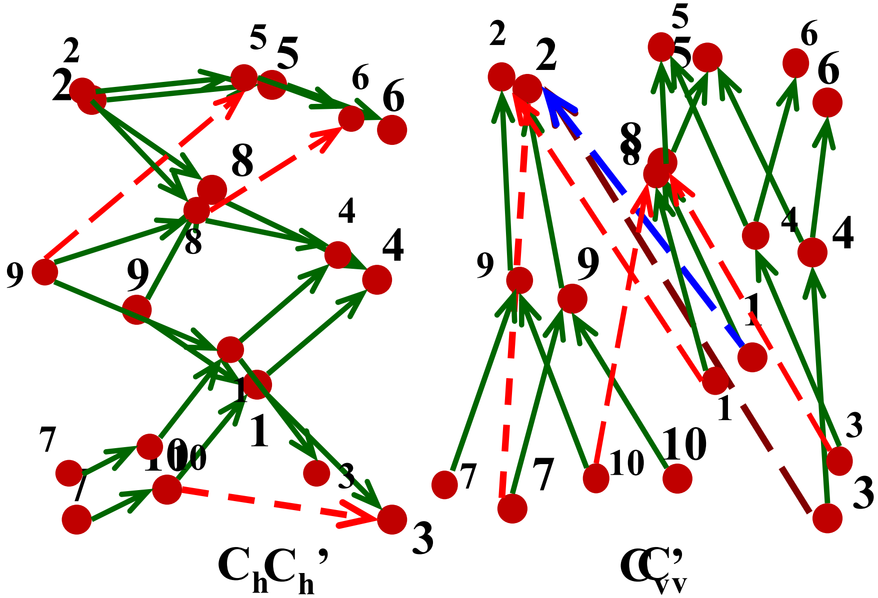
- Determine the geometrical relation of m_i and m_j depending on whether the two modules overlap:

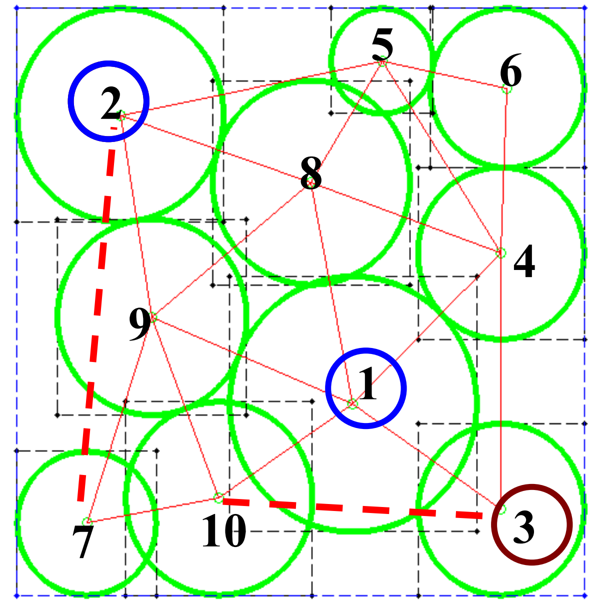
  1. overlap: based on the shape of the overlapped rectangle R_{ij}^o

  2. non-overlap: based on the shape of rectangle between the centers of two modules R_{ij}^s



IV. Local Legalization





- Some modules do not have geometric relations in the constructed constraint graphs:
  - It is not necessary to add geometric relations for all modules since there exist a low probability for modules in a far distance to overlap (for example: m_2 and m_3) .
- Add additional geometric relations for modules corresponding to nodes in neighboring triangles and without any relation (for example: m_2 and m_1)

IV. Local Legalization

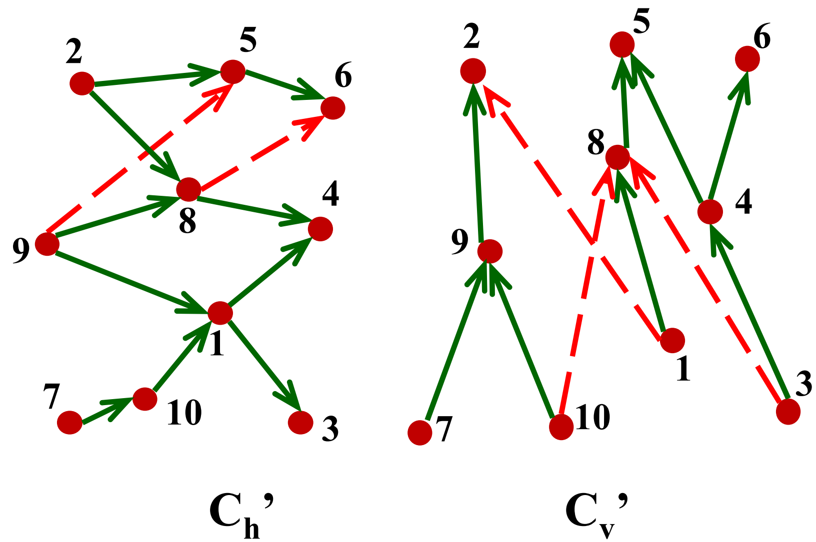
(ii) **Q**uadratic **O**ptimization **P**rogramming for **L**egalization **(QOPL)**

$$\min \{ (W - W_f)^2 + (H - H_f)^2 \}$$

s.t.,

$$x_i + w_i \le x_j \;, \quad \forall (n_i, n_j) \in C_h$$
$$y_i + h_i \le y_j \;, \quad \forall (n_i, n_j) \in C_v$$

$$x_s \ge 0, \quad \forall n_s \in N_s^h$$
$$x_e + w_e \le W, \quad \forall n_e \in N_e^h$$
$$y_s \ge 0, \quad \forall n_s \in N_s^v$$
$$y_e + h_e \le H, \quad \forall n_e \in N_e^h$$



N_s^h (N_s^v): set of nodes with zero in-degree in the horizontal (vertical) constraint graph

N_e^h (N_e^v): set of nodes with zero out-degree in the horizontal (vertical) constraint graph

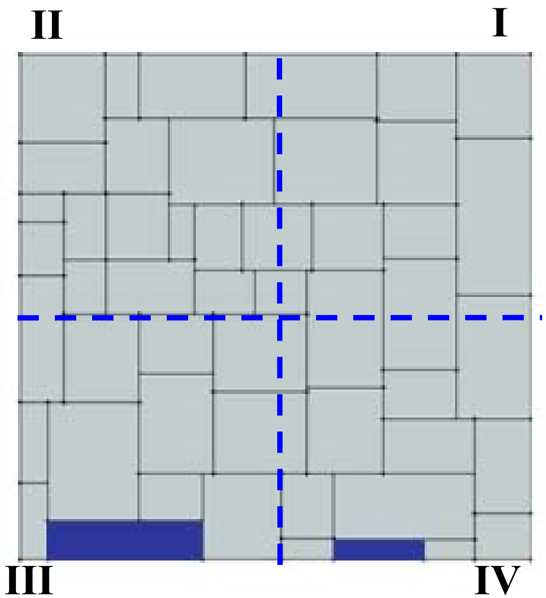
IV. Local Legalization

(iii) Hierarchical Flow

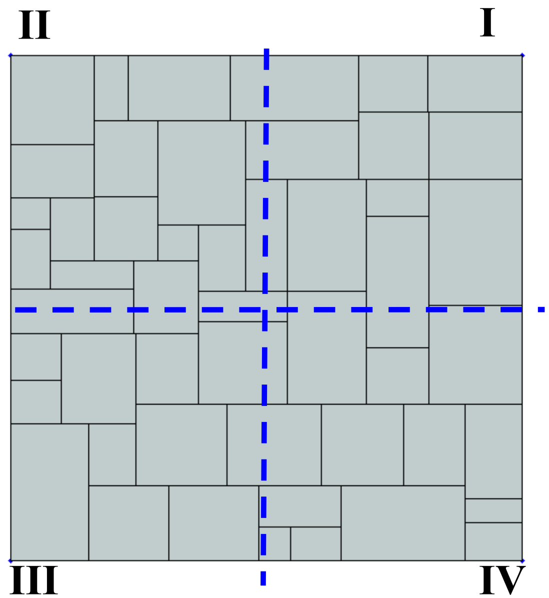
WHY ? aspect ratios aren't considered in the previous stages.

How? divide a region into subregions and redo global distribution on the subregions in which the violating modules exist.

Advantage: wirelength can be further reduced without changing the topology relations of modules in other subregions.



(a) Initial floorplan of n50.



(b) Hierarchical flow of n50.

Outline

V. Experimental Results

Use optimization function of Matlab library implement on a 1.6 GHz SUN Blade-2500 workstation with 4GB memory.

- Experimental Conditions:

  (1) dead space: 0%.

  (2) aspect ratio: 1 : 1

  (3) I/O pads are scaled to boundaries of a chip.

circuit	UFO							SAFFOA [13]			ZDS (PATOMA) [8]		
	with hierarchical flow			without hierarchical flow									
	Wire (mm)	Time (Sec)	# of violated modules	Wire (mm)	Δ (%)	Time (Sec)	# of violated modules	Wire (mm)	Δ (%)	Time (Sec)	Wire (mm)	Δ (%)	Time (Sec)
n10	45193	3	0	45193	0.00	3	0	46207	2.24	2	52258	15.63	1
n30	120110	57	0	122540	2.02	25	3	138218	15.08	14	156921	30.65	1
n50	143170	107	0	161990	13.15	48	2	165366	15.50	39	180115	25.80	1
n100	240430	391	0	259440	7.91	178	9	262469	9.17	158	283452	17.89	2
n200	385440	1587	0	428900	11.28	847	14	480573	24.68	690	505736	31.21	3
n300	526330	3441	0	540700	2.73	1939	7	551720	4.82	1563	566242	7.58	4
Avg.Δ	1			6.18				11.92			21.46		

Table 1: Wirelength and runtime comparisons (zero dead space, aspect ratio: 1:1).

V. Experimental Results

- Experimental Conditions:

  (1) dead space: 0%.

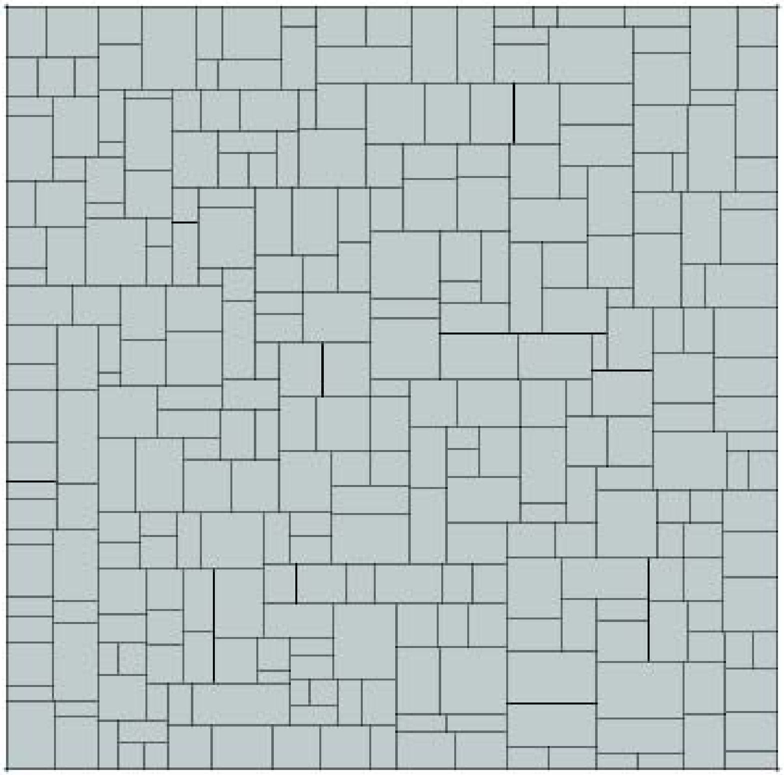
  (2) aspect ratios: 1 : 1 ; 2 : 1 ; 3 : 1 ; 4 : 1

  (3) I/O pads are scaled to boundaries of a chip.

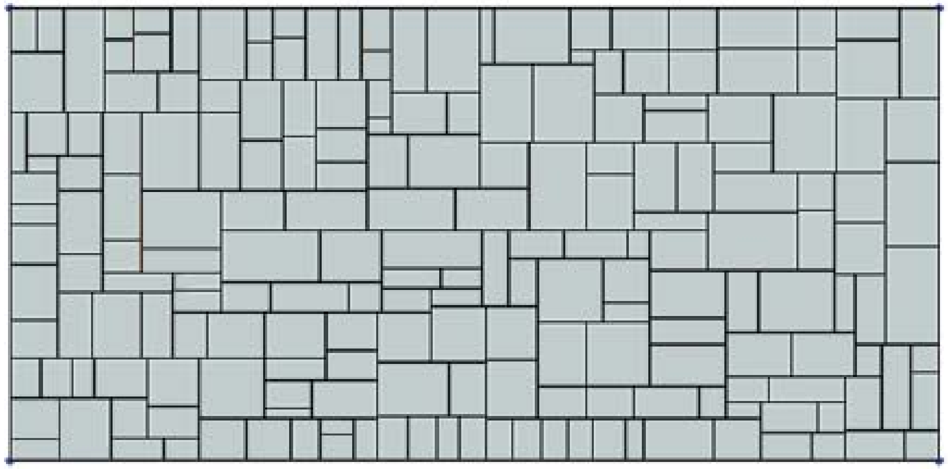
Circuit	1:1			2:1			3:1			4:1		
	UFO	SAFFOA	A-FP	UFO	SAFFOA	A-FP	UFO	SAFFOA	A-FP	UFO	SAFFOA	A-FP
	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)	Wire (mm)
n100	259440	263200	291628	262700	281509	290158	294220	296229	298894	286630	310752	313060
n200	428900	480014	572145	465800	520802	565927	532500	536040	583282	560090	572506	608074
n300	540700	554240	702822	592600	615713	722527	613070	617554	793771	702890	714746	858346
ami33	50699	59431	74072	52252	62272	75168	55827	67364	75180	57207	74067	79525
ami49	671920	625541	799239	687611	641746	829888	699540	675540	880387	715415	698811	939049
Avg.Δ	1	5.25%	28.17%	1	7.07%	23.68%	1	3.86%	20.22%	1	7.89%	31.26%

Table 2: Wirelength comparisons on the outlines with different aspect ratios.

V. Experimental Results



(a)



(b)

Fixed-outline with zero dead space in (a) n300 (aspect ratio = 1:1)
(b) n200 (aspect ratio = 2:1)

Outline

I. Introduction
II. Problem Formulation
III. Global Distribution
IV. Local Legalization
V. Experimental Results
VI. Conclusions

VI. Conclusion

- We have proposed two convex optimization algorithms for fixed-outline floorplanning, named **UFO**.
- **UFO** can handle fixed-outline floorplanning with zero-dead space.
- Experimental results have shown that **UFO** outperforms than other floorplaners.
- Feature work:
  (a) **UFO** for large scale design
  (b) **UFO** considering the pre-placed constraint

Thanks for
Your Attendance