



SafeChoice: **A Novel Clustering Algorithm for Wirelength-Driven Placement**

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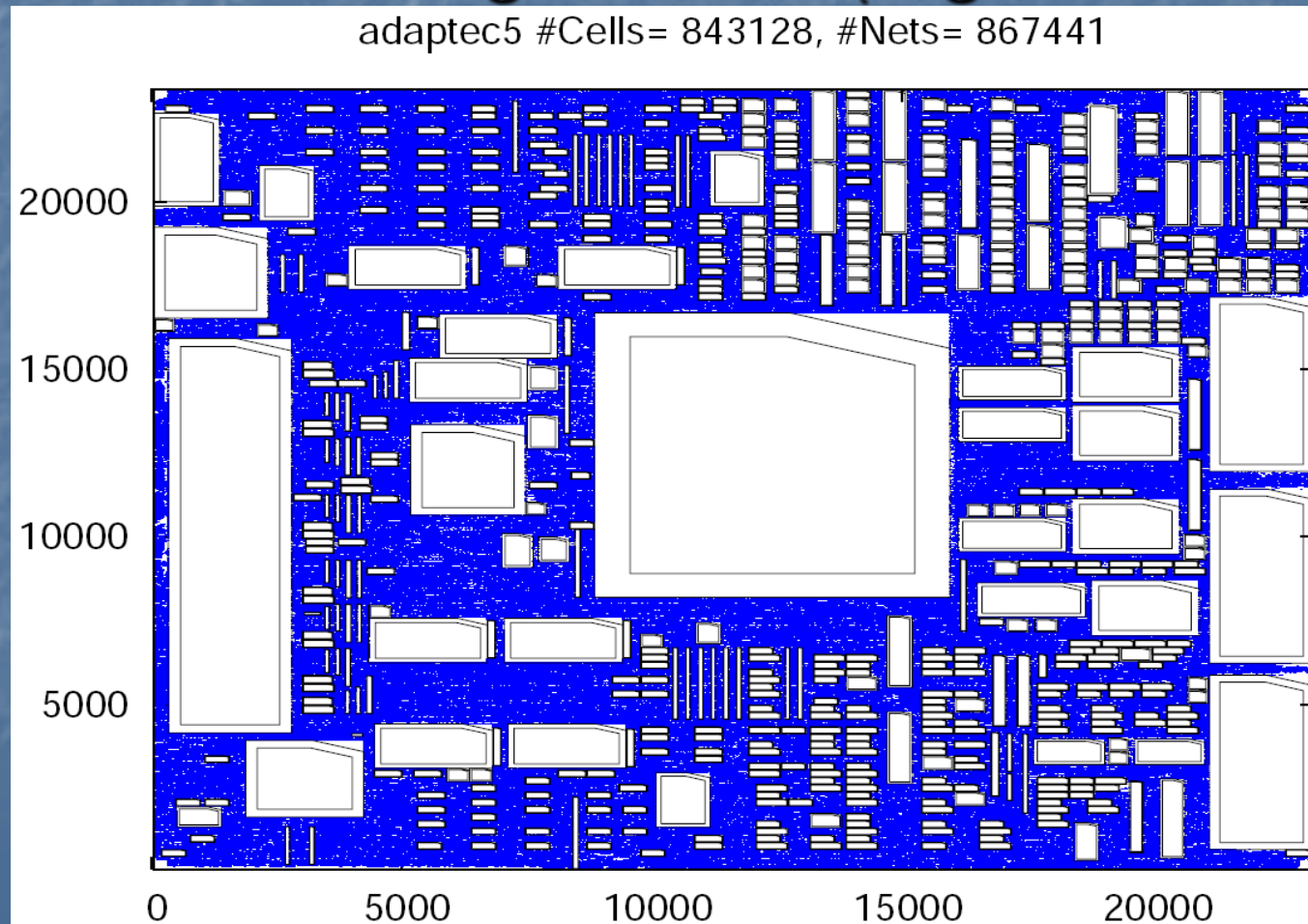
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Modern VLSI Placement

- **Millions** of standard cells (e.g., logic gates)
- **Hundreds** of big macros (e.g., IP cores)





What is Clustering?

- Form small objects into bigger clusters and send the clustered netlist to the placer
- Essential part of modern placers
 - **Cut down problem size**
 - **If clusters are formed correctly, it will guide the placer to generate better layout**

Previous Clustering Algorithms

Clustering Algorithm	Used in Placer / Partitioner	Directly Handle Hyperedge	Priority Queue
Edge Coarsening (EC) [G. Karypis et.al, DAC 1997]	hMetis	No	No
First Choice (FC) [G. Karypis et.al, DAC 1999]	hMetis / NTUplace3 / Capo10.5	No	No
Edge Separability (ESC) [J. Cong et.al, TCAD 2004]	---	No	Yes
Fine Granularity (FG) [B. Hu et.al, TCAD 2004]	mFAR	No	Yes
Best Choice (BC) [G.-J. Nam et.al, TCAD 2006]	APLace / mPL6 / FastPlace3 / RQL	No	Yes
Net Cluster (NC) [J. Li et.al, ISPD 2007]	---	Yes	No

Common Problem in Previous Work

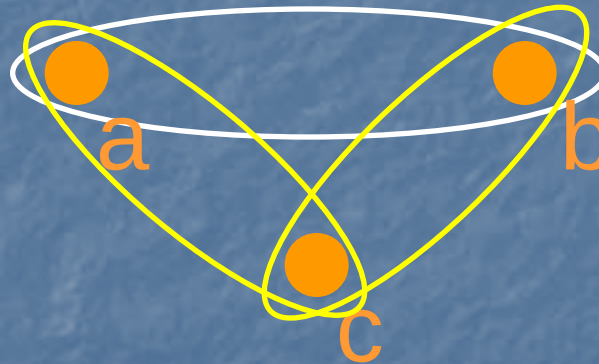
- Based on a heuristic assumption

Cluster highly directly connected objects



Minimize placement wirelength

*Indirect
Connections*



X mislead placers to a low-quality solution

SafeChoice (SC) Overview

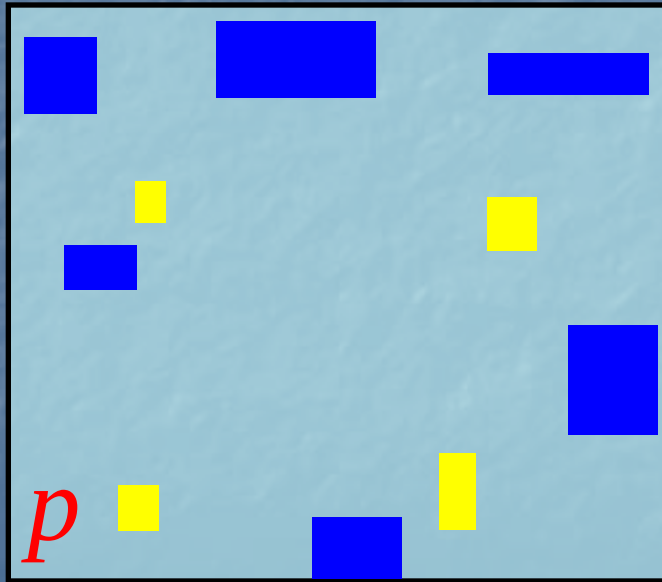
- Specifically designed for wirelength-driven placement
- Priority queue (PQ) based
- Handling hyperedges directly
- Main Features
 - ◆ Safe Clustering
 - ◆ Safe Condition
 - ◆ Selective Enumeration
 - ◆ Smart Stopping Criterion
- Best clusters for HPWL (SC vs. FC, BC & NC)
- Best HPWL (SCPlace vs. all state-of-the-art placers)

Guarantee

Concept of Safe Clustering

- $G(V, E)$
- P
- $V_c \subseteq V$

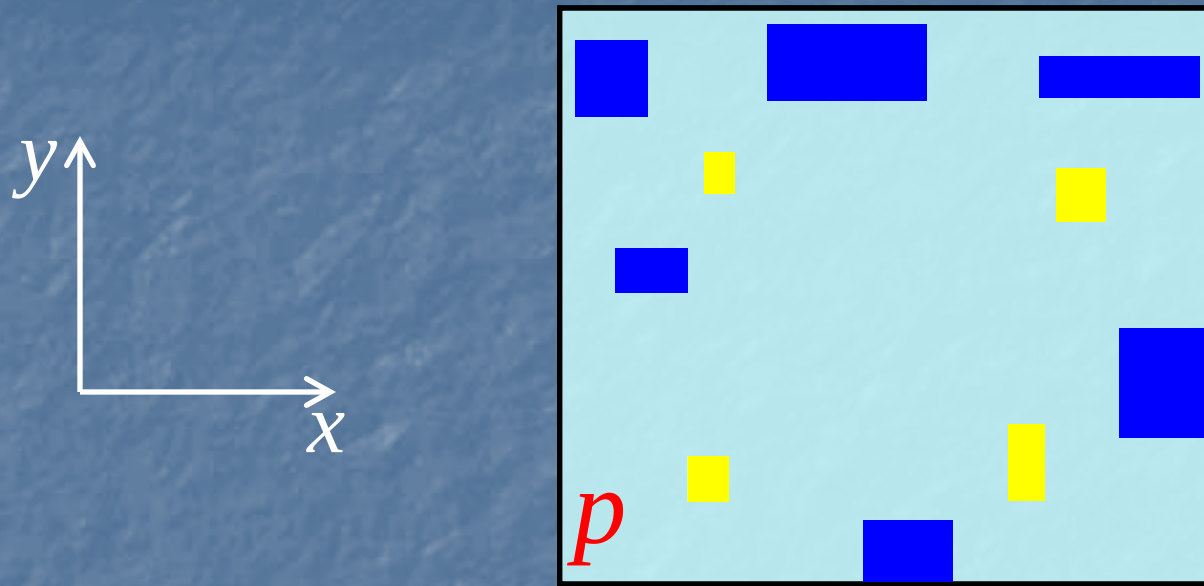
If the optimal wirelength in the clustered netlist is equal to the optimal wirelength in the original netlist, then it is safe to cluster V_c



For $\forall p \in P$, if V_c can be moved to the same location without increasing the wirelength, then it is safe to cluster V_c

*ignore overlap issue
in the cluster*

Horizontally / Vertically Safe



Horizontally Safe



Vertically Safe



Safe

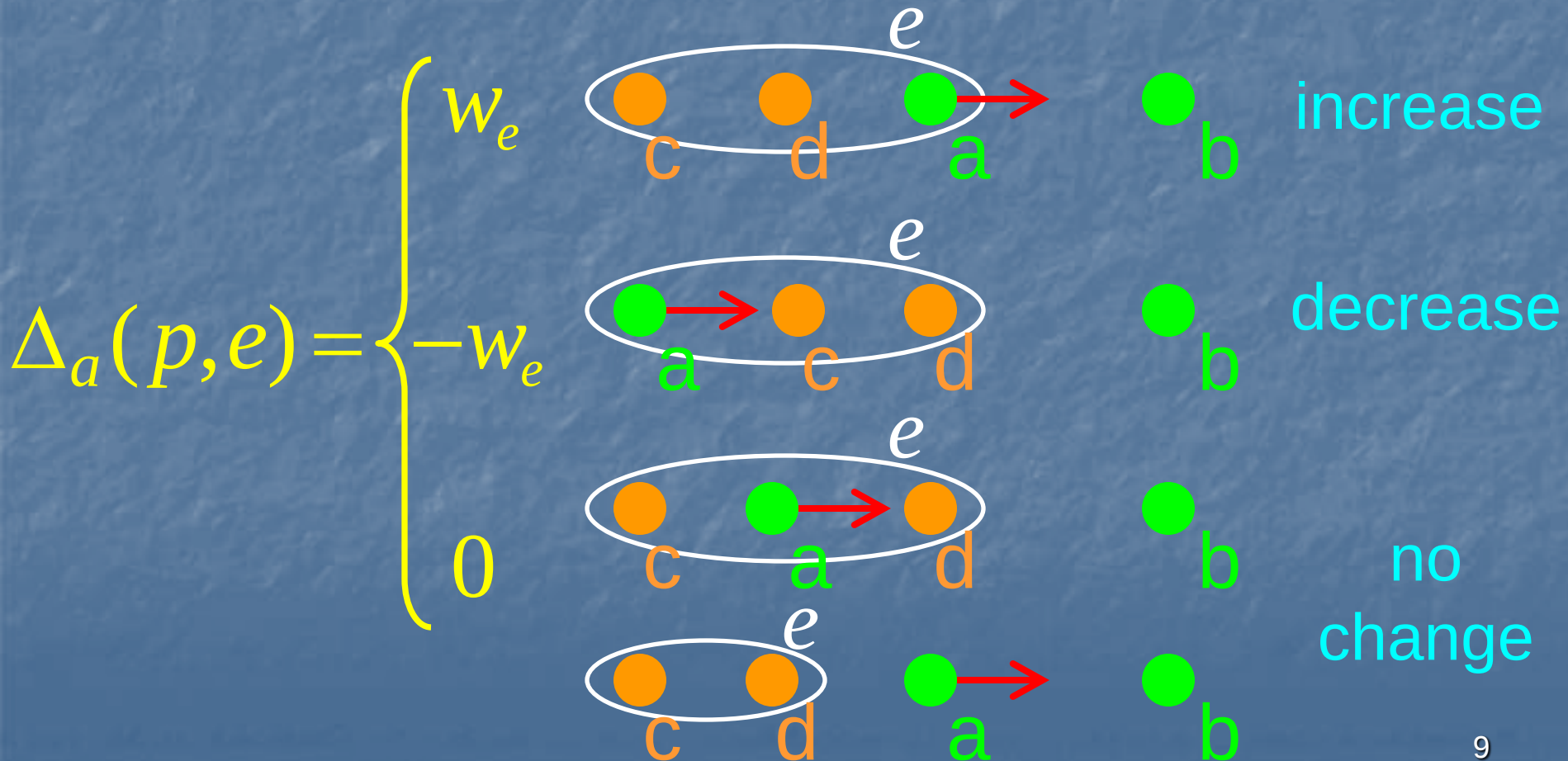
Assumptions:

- ignore overlap issue
- ignore fixed objects
- $V_c = \{a, b\}$

Wirelength Gradient Function

- $p \in P$
- $e \in E$
- $w_e \geq 0$
- $V_c = \{a, b\}$

$\Delta_a(p, e)$: HPWL change of e a is moving towards b $\Delta_b(p, e)$: HPWL change of e b is moving towards a



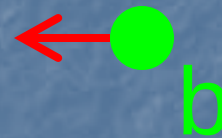
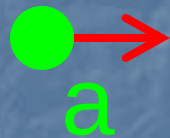
Total Wirelength Gradient Function

- $v \in V, E_v = \text{set of hyperedges incident to } v$

$$F_{ab}(p) = \min\left(\sum_{e \in E_a} \Delta_a(p, e), \sum_{e \in E_b} \Delta_b(p, e)\right)$$



Find out the **smaller** total HPWL change between either moving a towards b or moving b towards a



$$\text{if } F_{ab}(p) \begin{cases} = \sum_{e \in E_a} \Delta_a(p, e) \leq 0 & \text{HPWL}_{total} \text{ no increase} \\ = \sum_{e \in E_b} \Delta_b(p, e) \leq 0 & \text{HPWL}_{total} \text{ no increase} \\ > 0 & \text{HPWL}_{total} \text{ increase} \end{cases}$$

Safe Condition for $V_c=\{a,b\}$

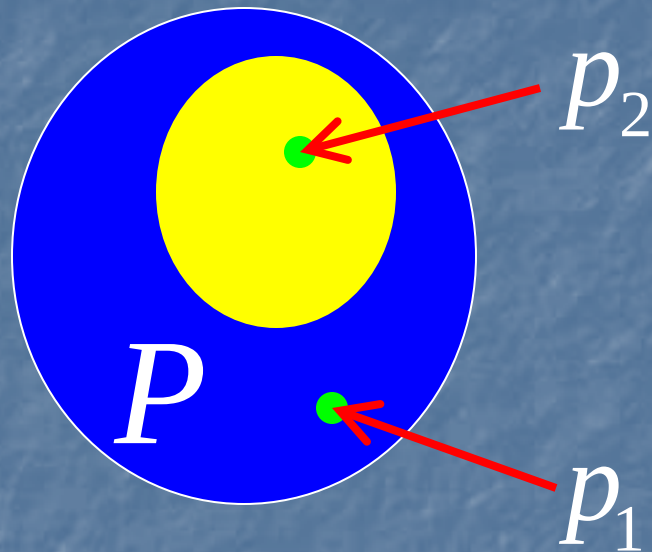
It is safe to cluster a and b if $\forall p \in P, F_{ab}(p) \leq 0$



$$F_{ab}(p_a) = \sum_{e \in E_a} \Delta_{ba}((p_a, e)) \leq 0$$

$\forall p \in P \Rightarrow$ **Impractical**

Principle in Selective Enumeration



$$\forall p \in P, F_{ab}(p) \leq 0$$

Only the placement p with the **maximum** $F_{ab}(p)$ matters

$$p_1 \in P, p_2 \in P \quad \text{if} \quad F_{ab}(p_1) \leq F_{ab}(p_2)$$

then p_1 would not affect the safe condition, and thus can be ignored in the enumeration

Enumeration Size Cut Down

Enumeration Size:

$$|P| = \infty$$

↓ ignore $V_{\bar{a}\bar{b}}$
use one position to substitute
various positions in each interval

$$3^{|V_{ab}|}$$

↓ ignore the central
interval

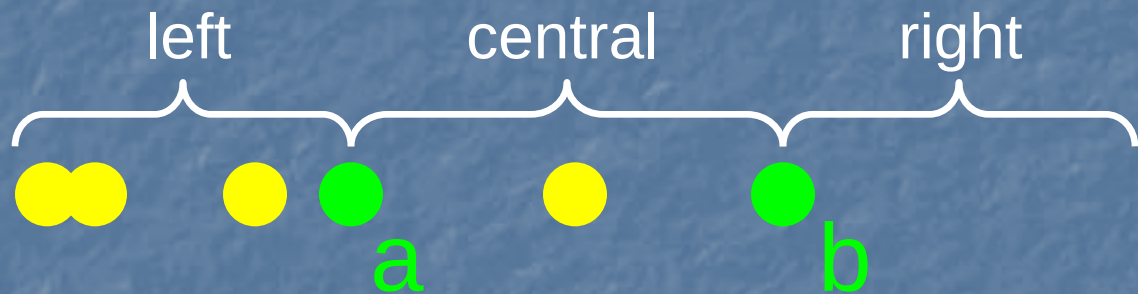
$$2^{|V_{ab}|}$$

↓ fixing 3 categories
of vertices

$$2^{|V_{ab}| - \alpha}$$

- $V_{\bar{a}\bar{b}}$: connect with neither a nor b

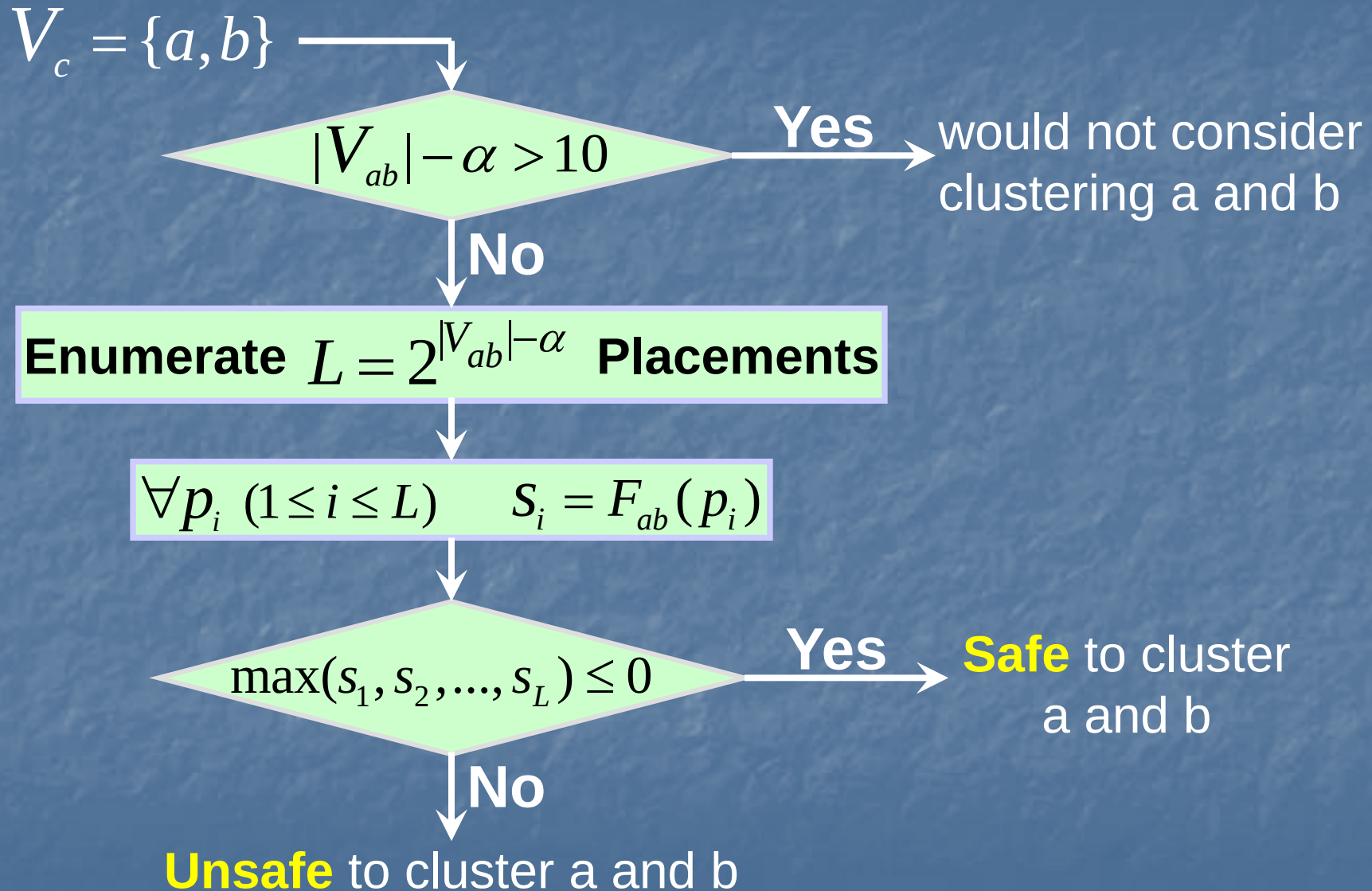
- V_{ab} : connect with a or b or both



placement p'

$$F_{ab}(p) = F_{ab}(p')$$

Flow of Selective Enumeration



SafeChoice Algorithm

- Consider both safeness and area

$$C(a,b) = S^* + \theta \times \frac{A_a + A_b}{A_s} \quad (\theta = 4 \text{ by default})$$

- Priority queue (PQ) based
- Three operation modes

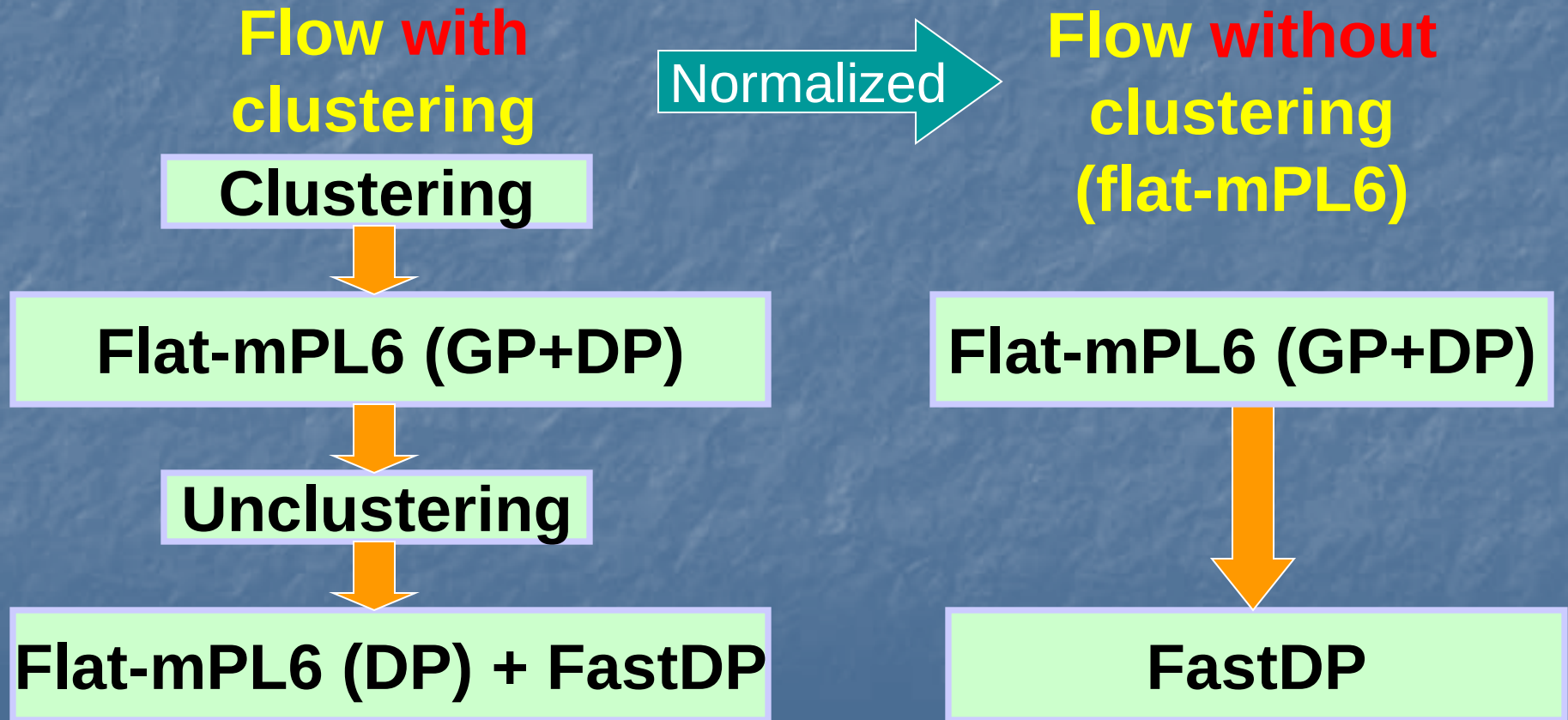
Mode	Objective	Stopping Criterion
Safety Guarantee [SC-G]	Generate safe clusters only	No more safe clusters in PQ
Clustering Ratio [SC-R]	Achieve various clustering ratio	Target clustering ratio is reached
Smart Mode [SC] (default)	Achieve best HPWL	Threshold cost is reached $C_t = 21$

Experiments Setup

- All experiments run on a Linux machine (Intel Xeon 2.83 GHz CPU and 32 GB RAM)
- ISPD05/06 Placement Benchmarks (use scaled HPWL for ISPD06 circuits)
- Two categories of experiments
 - Compare SafeChoice with clustering algorithms
 - Compare SCPlace with placement algorithms

Experimental Flow for Clustering

- Compared with FirstChoice (FC), BestChoice (BC), NetCluster (NC)
- mPL6 as placement engine



SC-R vs. FC, BC & NC

Normalized Clustering Time

FC	BC	NC	SC-R
0.545	2.475	0.813	1

Normalized HPWL

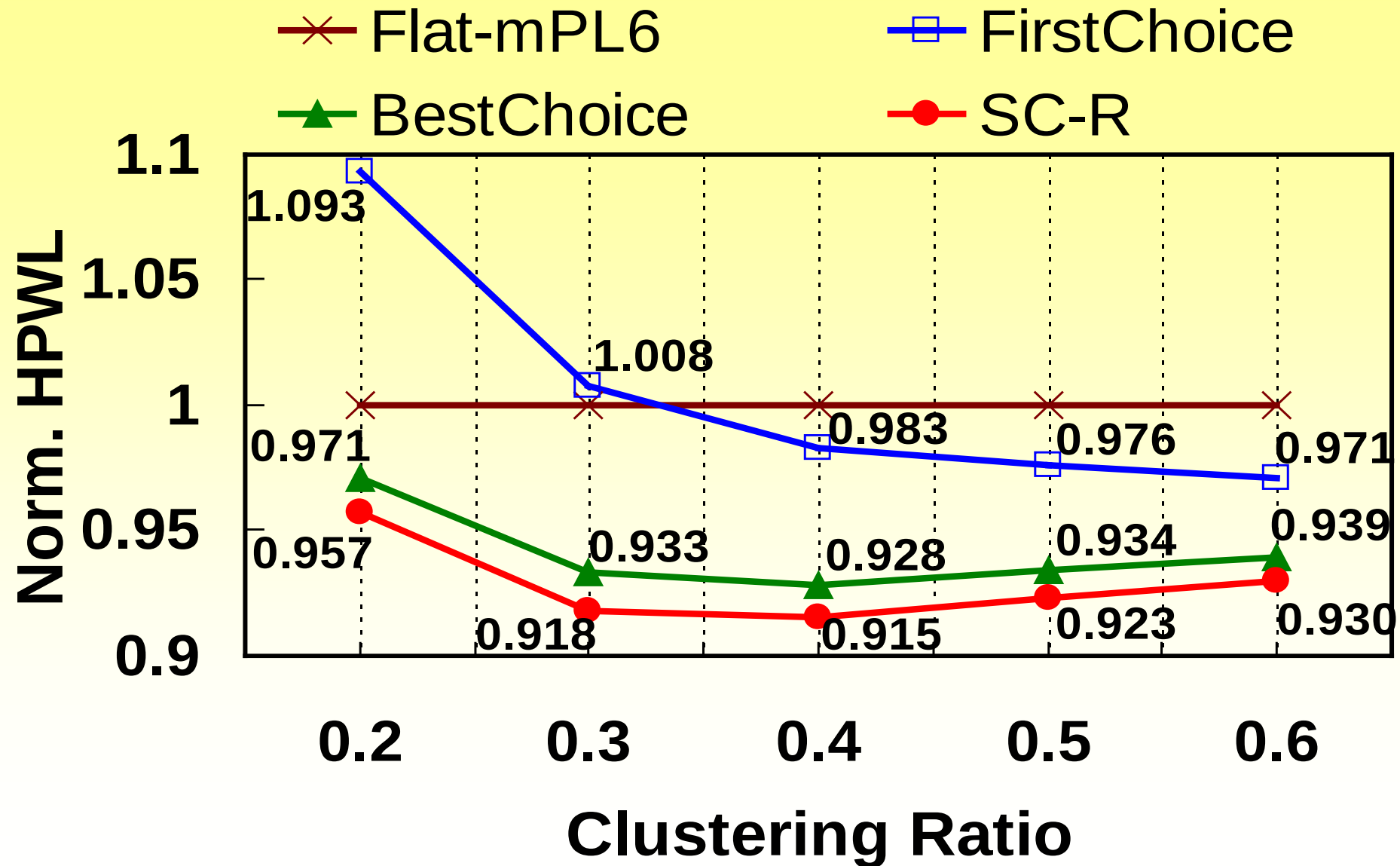
FC	BC	NC	SC-R
0.971	0.937	0.978	0.928

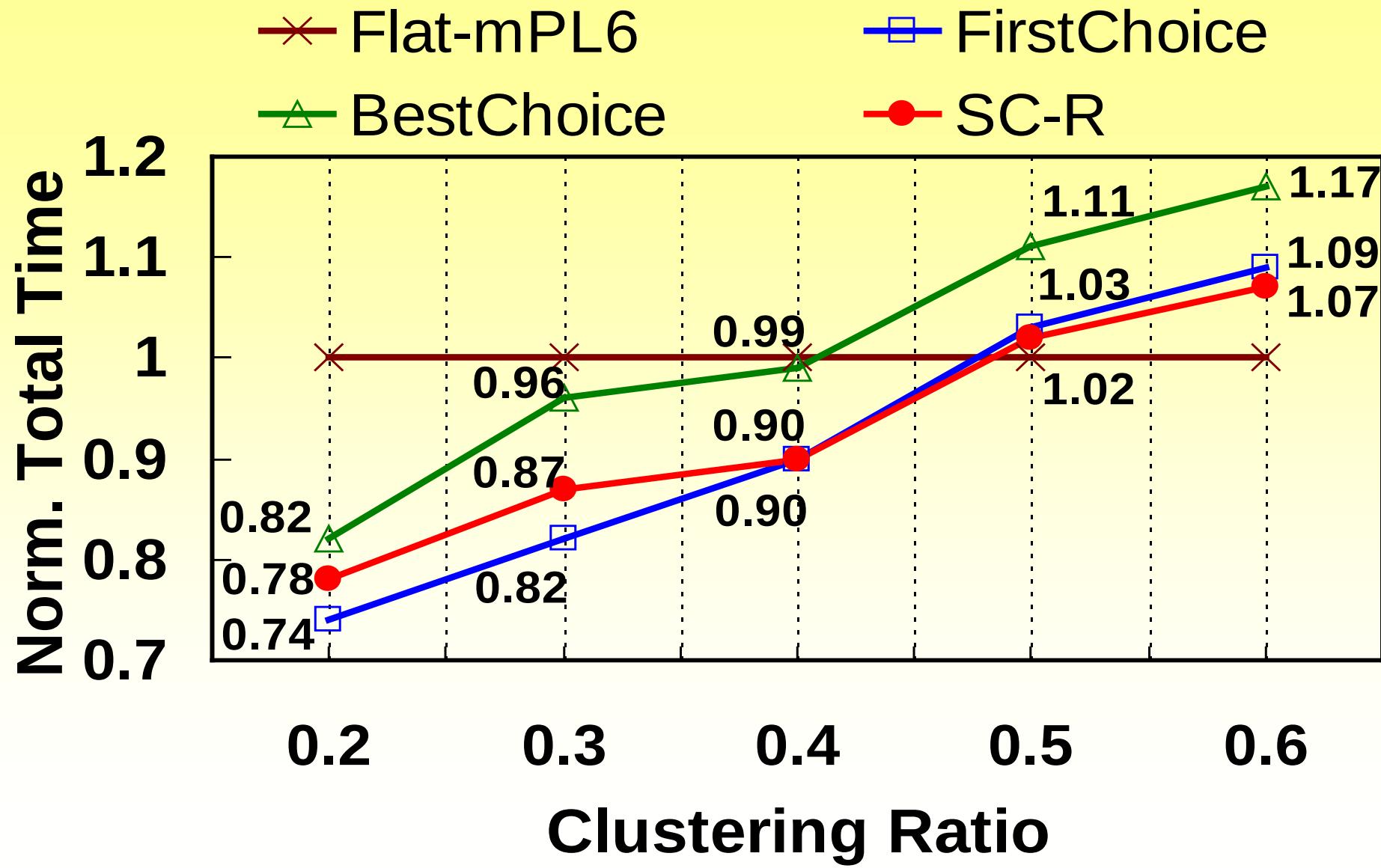
Normalized Total Time

FC	BC	NC	SC-R
1.000	1.056	0.940	0.985

Circuit	Clustering Ratio
adaptec1	0.6381
adaptec2	0.5764
adaptec3	0.5677
adaptec4	0.5382
bigblue1	0.6128
bigblue2	0.5977
bigblue3	0.5074
bigblue4	0.5617
adaptec5	0.5569
newblue1	0.5674
newblue2	0.5886
newblue3	0.5462
newblue4	0.6357
newblue5	0.5505
newblue6	0.5836
newblue7	0.5634

**Average
Clustering
Ratio: 0.57**





SC vs. Multilevel mPL6

Circuit	HPWL (x10e6)		Total Time (s)	
	SC	mPL6+FastDP	SC	mPL6+FastDP
adaptec1	78.51	76.47	1238	1807
adaptec2	88.51	89.19	2064	2032
adaptec3	207.27	206.00	3732	6187
adaptec4	184.33	187.51	3227	5687
bigblue1	95.31	95.14	1319	2208
bigblue2	146.07	146.57	4183	5992
bigblue3	357.56	331.70	10516	8842
bigblue4	803.43	806.83	15460	19457
adaptec5	461.99	429.97	5919	10796
newblue1	88.10	64.72	7490	2567
newblue2	198.35	198.90	6303	7141
newblue3	287.76	283.25	14986	9644
newblue4	351.02	301.89	6053	9481
newblue5	624.26	526.98	8405	16220
newblue6	498.44	516.43	11081	13566
newblue7	1042.97	1070.08	21049	32561
Norm.	0.910	0.879	1.086	1.412

SCPlace vs. RQL & mPL6

Circuit	HPWL (x10e6)			Total Time (s)	
	RQL	mPL6	SCPlace	mPL6	SCPlace
adaptec1	77.82	78.05	76.50	1769	937
adaptec2	88.51	91.76	86.30	1940	1504
adaptec3	210.96	214.29	204.10	5949	2981
adaptec4	188.86	194.25	183.20	5487	2652
bigblue1	94.98	96.75	93.58	2158	1182
bigblue2	150.03	152.33	144.39	5842	3345
bigblue3	323.09	343.89	336.01	8382	7682
bigblue4	797.66	829.42	790.76	18590	12486
adaptec5	443.28	430.42	419.72	10714	5528
newblue1	64.43	73.21	77.27	2489	10798
newblue2	199.60	201.63	194.66	7109	4642
newblue3	269.33	284.04	281.59	9508	13736
newblue4	308.75	302.04	295.98	9410	4272
newblue5	537.49	536.29	522.71	16085	10149
newblue6	515.69	521.28	494.10	13457	10877
newblue7	1057.79	1083.66	1035.15	32372	23356
Norm.	1.01	1.04	1	1.54	1

SCPlace: Two-level placement algorithm based on SafeChoice and flat-mPL6 (SCPlace will be described in the future journal paper)

SCPlace vs. Best Approach

Circuit	HPWL (x10e6)		
	Previously the Best		SCPlace
adaptec1	RQL	77.82	76.50
adaptec2	RQL	88.51	86.30
adaptec3	RQL	210.96	204.10
adaptec4	RQL	188.86	183.20
bigblue1	RQL	94.98	93.58
bigblue2	RQL	150.03	144.39
bigblue3	RQL	323.09	336.01
bigblue4	RQL	797.66	790.76
adaptec5	mPL6	431.14	419.72
newblue1	NTUplace3	61.08	77.27
newblue2	APlace3	198.24	194.66
newblue3	RQL	269.33	281.59
newblue4	mPL6	299.66	295.98
newblue5	NTUplace3	509.54	522.71
newblue6	RQL	515.69	494.10
newblue7	RQL	1057.79	1035.15
Norm.		1.00	1

Placer	Normalized HPWL
Capo10.5	1.25
Dragon	1.21
APlace3	1.10
mFAR	1.09
Kraftwerk	1.07
mPL6	1.03
NTUplace3	1.02
RQL	1.01
SCPlace	1

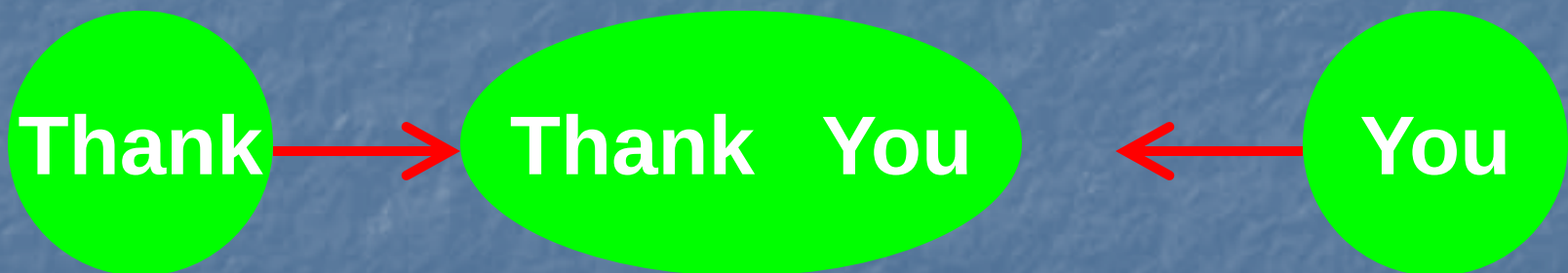
Results of other placers are cited from RQL paper [N.Viswanathan et.al, DAC 2007]

Conclusion

- **SafeChoice** – a novel clustering algorithm for wirelength-driven placement
 - Safe Clustering
 - Safe Condition
 - Selective Enumeration
 - Smart Stopping Criterion
- Promising experimental results
- **Best clusters for HPWL** (SC VS. FC, BC & NC)
- **Best HPWL** (SCPlace VS. all state-of-the-art placers)

Future Work

- Derive the safe condition for $V_c = \{a, b, c\}$
- Develop our own placer based on SafeChoice
- Integrate into other algorithms (e.g., partitioning)
- SafeChoice source code is publicly available at [*www.public.iastate.edu/~zijunyan/*](http://www.public.iastate.edu/~zijunyan/)



Backup

Mode	Objective	S^*	Stopping Criterion
Safety Guarantee [SC-G]	Safe clusters	$S_{\max}$	No more safe clusters in PQ
Clustering Ratio [SC-R]	Clustering ratio	$\bar{s} = \frac{\sum_{i=1}^L s_i}{L}$	Target clustering ratio is reached
Smart Mode [SC] (default)	Best HPWL	$\bar{s} = \frac{\sum_{i=1}^L s_i}{L}$	Threshold cost $C_t \leq 21$

$$s_{\max} = \max(s_1, s_2, \dots, s_L)$$

Enumeration Size Cut Down

Enumeration Size:

$$|P| = \infty$$

↓ ignore $V_{\bar{a}\bar{b}}$
use one position to substitute
various positions in each interval

$$3^{|V_{ab}|}$$

↓ ignore the central
interval

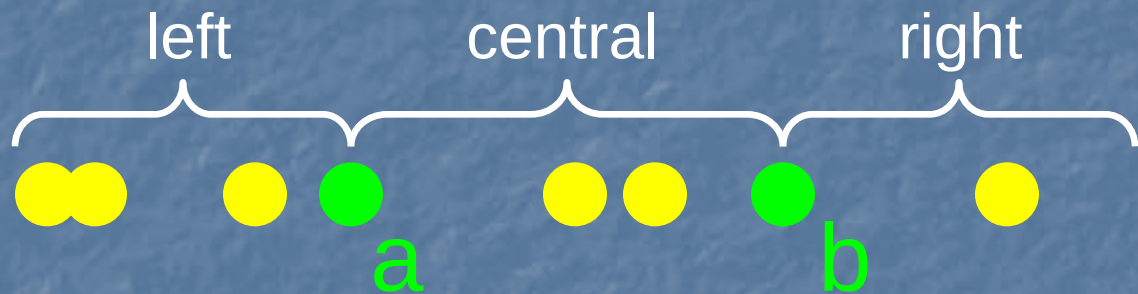
$$2^{|V_{ab}|}$$

↓ fixing 3 categories
of vertices

$$2^{|V_{ab}| - \alpha}$$

- $V_{\bar{a}\bar{b}}$: connect with neither a nor b

- V_{ab} : connect with a or b or both



placement p'

$$F_{ab}(p) \leq F_{ab}(p')$$

Enumeration Size Cut Down

Enumeration Size:

$$|P| = \infty$$

ignore $V_{\bar{a}\bar{b}}$
 ignore various position
 in each interval for V_{ab}

$$3^{|V_{ab}|}$$

ignore positions in
 central interval

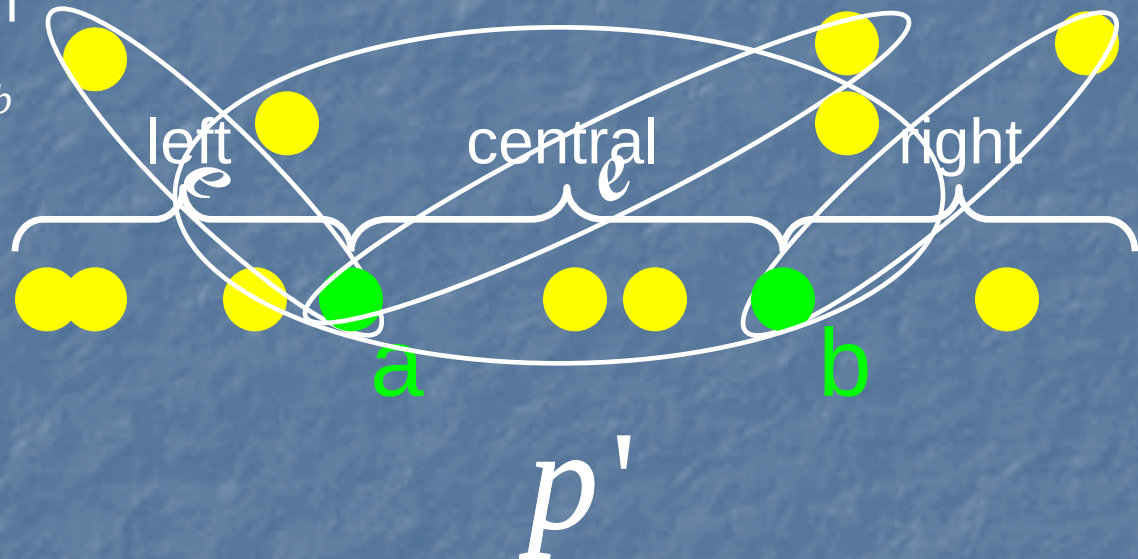
$$2^{|V_{ab}|}$$

fixing 3 categories
 of vertices

$$2^{|V_{ab}| - \alpha}$$

- $V_{\bar{a}\bar{b}}$: connect with neither a nor b

- V_{ab} : connect with a or b or both



$$F_{ab}(p) F_{ab}^{-}(w_e) \leq F_{ab}(p') = w_e$$

SC-G vs. FC & BC

Normalized Clustering Time

FC	BC	SC-G
1.006	5.303	1

Normalized HPWL

FC	BC	SC-G
0.974	0.944	0.963

Some unsafe clusters have better area than safe clusters

$$C_{unsafe} < C_{safe}$$

Normalized Total Time

FC	BC	SC-G
1.381	1.413	1.258

Circuit

Clustering Ratio

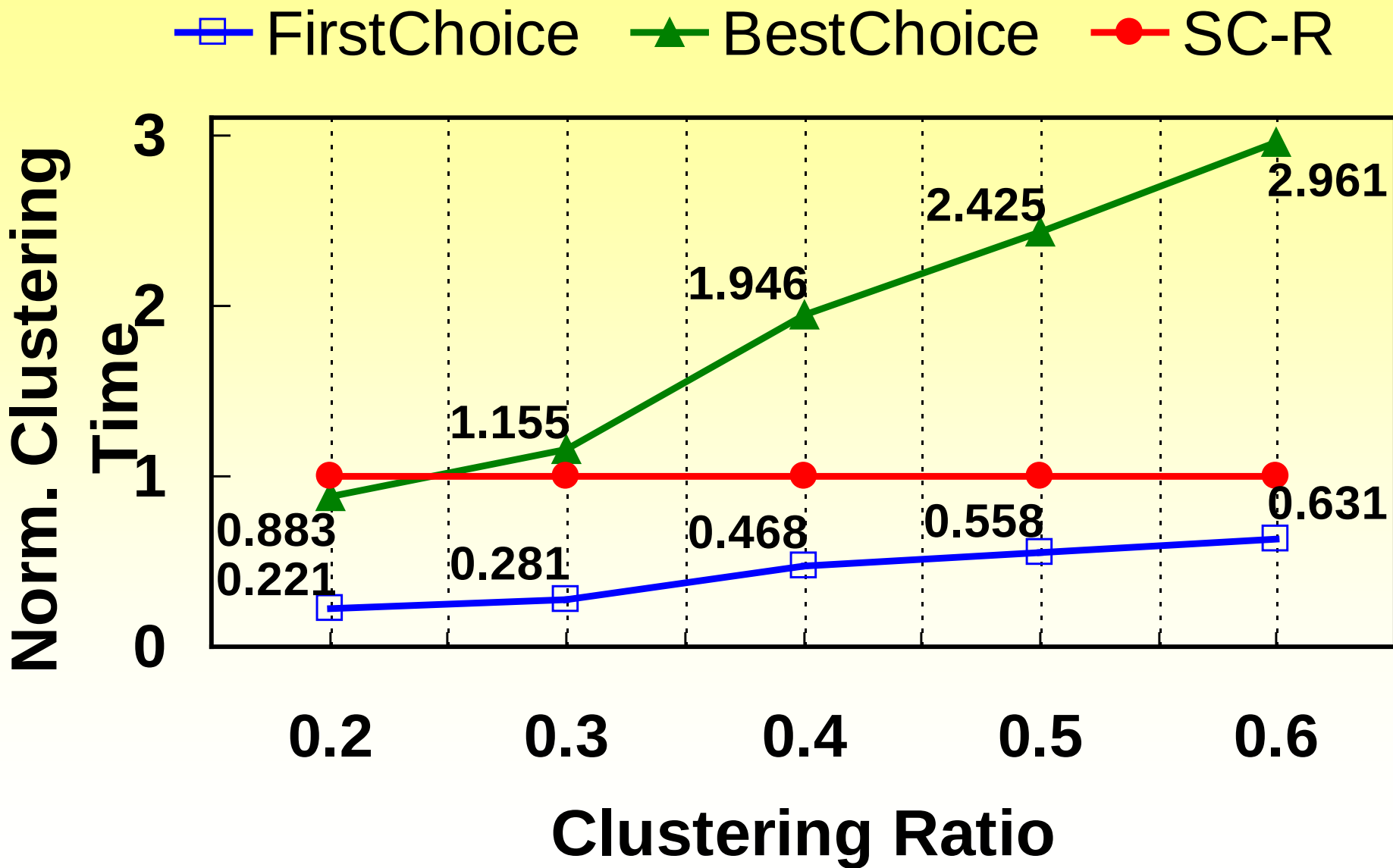
adaptec1	0.80
adaptec2	0.77
adaptec3	0.71
adaptec4	0.62
bigblue1	0.77
bigblue2	0.73
bigblue3	0.58
bigblue4	0.64
adaptec5	0.68
newblue1	0.78
newblue2	0.68
newblue3	0.65
newblue4	0.71
newblue5	0.66
newblue6	0.74
newblue7	0.64

Average
Clustering
Ratio: 0.70

Clustering for Various Clustering Ratio

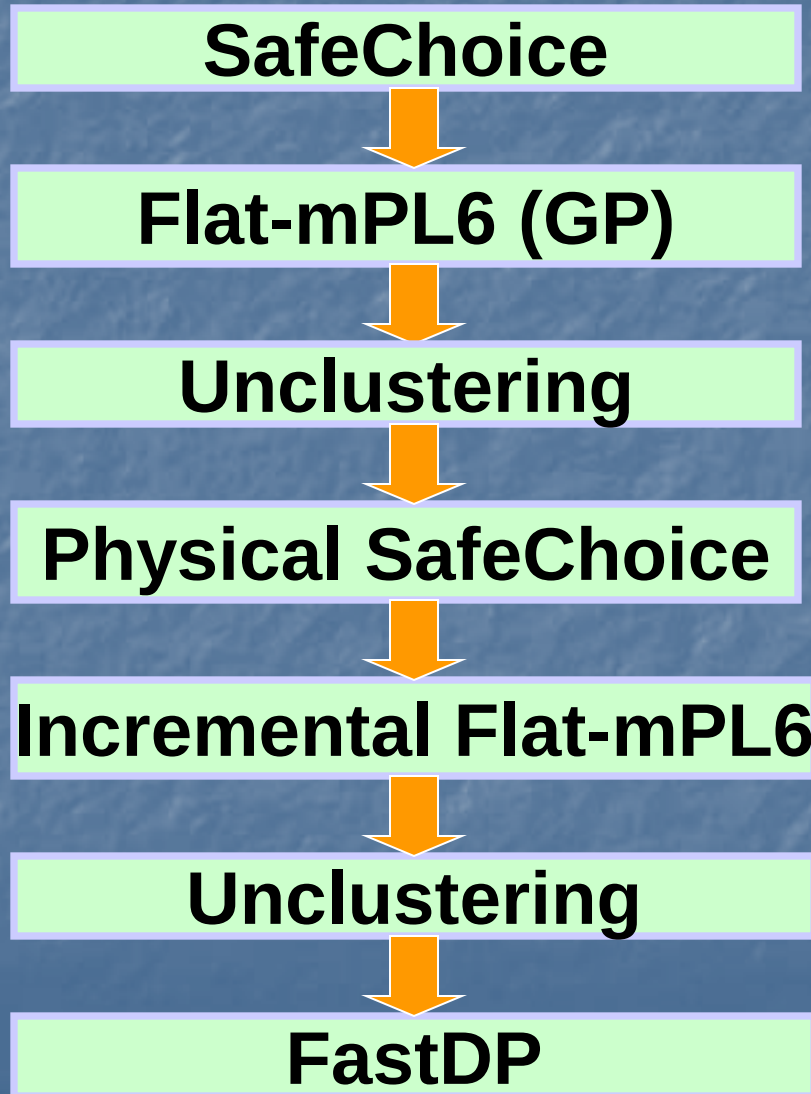
- Compare with FC and BC
- Target clustering ratio $\gamma = 0.2, 0.3, 0.4, 0.5, 0.6$

Circuit	Clustering Ratio γ	Clustering Time(s)			Normalized HPWL			Normalized Total Time		
		FC	BC	SC-R	FC	BC	SC-R	FC	BC	SC-R
newblue1	0.2	169	806	781	0.91	0.88	0.81	0.13	0.24	0.23
	0.3	149	718	527	0.91	0.86	0.80	0.23	0.49	0.41
	0.4	127	630	226	0.91	0.87	0.81	0.30	0.57	0.39
	0.5	104	538	141	0.93	0.89	0.84	0.91	1.30	0.96
	0.6	84	434	93	0.94	0.90	0.96	1.05	1.31	1.04



SC-Based Two-Level Placement

Flow of SCPlace



- Based on *physical* SafeChoice

← Level 1

So Simple!

← Level 2

Details of physical
SafeChoice and SCPlace
can be found in the future
journal paper