Futures for Partitioning in Physical Design

Andrew B. Kahng
UCLA CS Dept.
ISPD-98

http://vlsicad.cs.ucla.edu/~abk

Structure

- This tutorial: 30 minutes
- Panelist talks: 30 minutes
- Your questions: 30 minutes

Why a Partitioning Tutorial ?

- Partitioning is basic to divide and conquer
- Significant advances in past few years
- Changing context
  - top-down design methodology
  - physical attributes of problem

Outline of Talk

- Where are we now?
  - formulations
  - algorithms
  - AlpertK95, Johannes96
- Consequences of technology
  - top-down design context
  - spatial embedding context
- Role of partitioning
- Futures: formulations, objectives, algorithms
- Questions for the panel

Standard Min-Cut Formulation

- Given a vertex- and hyperedge-weighted hypergraph $H = (V, E)$, partition V into disjoint clusters $C_1, \ldots, C_k$, such that the number of cut hyperedges is minimized.
- Edge is *cut* if there exist C_i, C_j with
- $k = 2$ most often studied
- Cluster sizes must satisfy balance constraints
- Focus on cut: communication, interaction between subproblems

Variant Formulations

- Constraints
  - I/O, area
  - path delay / hopcount
  - multi-balance (area, power)
  - multi-dimensional balance
  - hierarchy
- Degrees of freedom
  - replication
- Objectives
  - min-cut ?

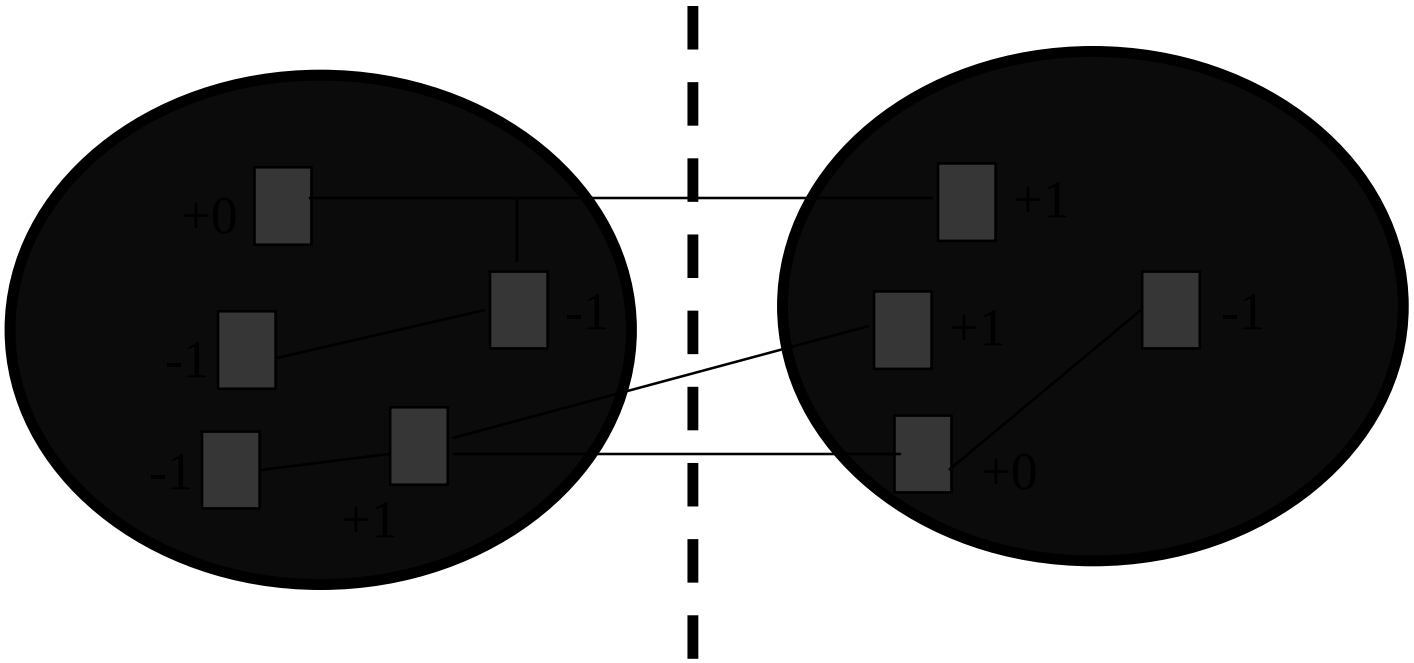
Iterative Algorithms

- Neighborhood operator
  - single-shift
  - pair-swap
  - pass
    - start with all vertices unlocked
    - do
    - make the best move of unlocked vertices
    - lock moved vertices
    - until all vertices locked
    - find best prefix of this move sequence
    - actually make this “compound move”
- Accept/reject ?

Iterative Algorithms

- Folklore greedy shift, swap
- 1970 Kernighan-Lin
- 1982 Fiduccia-Mattheyses

FM: The Industry Standard

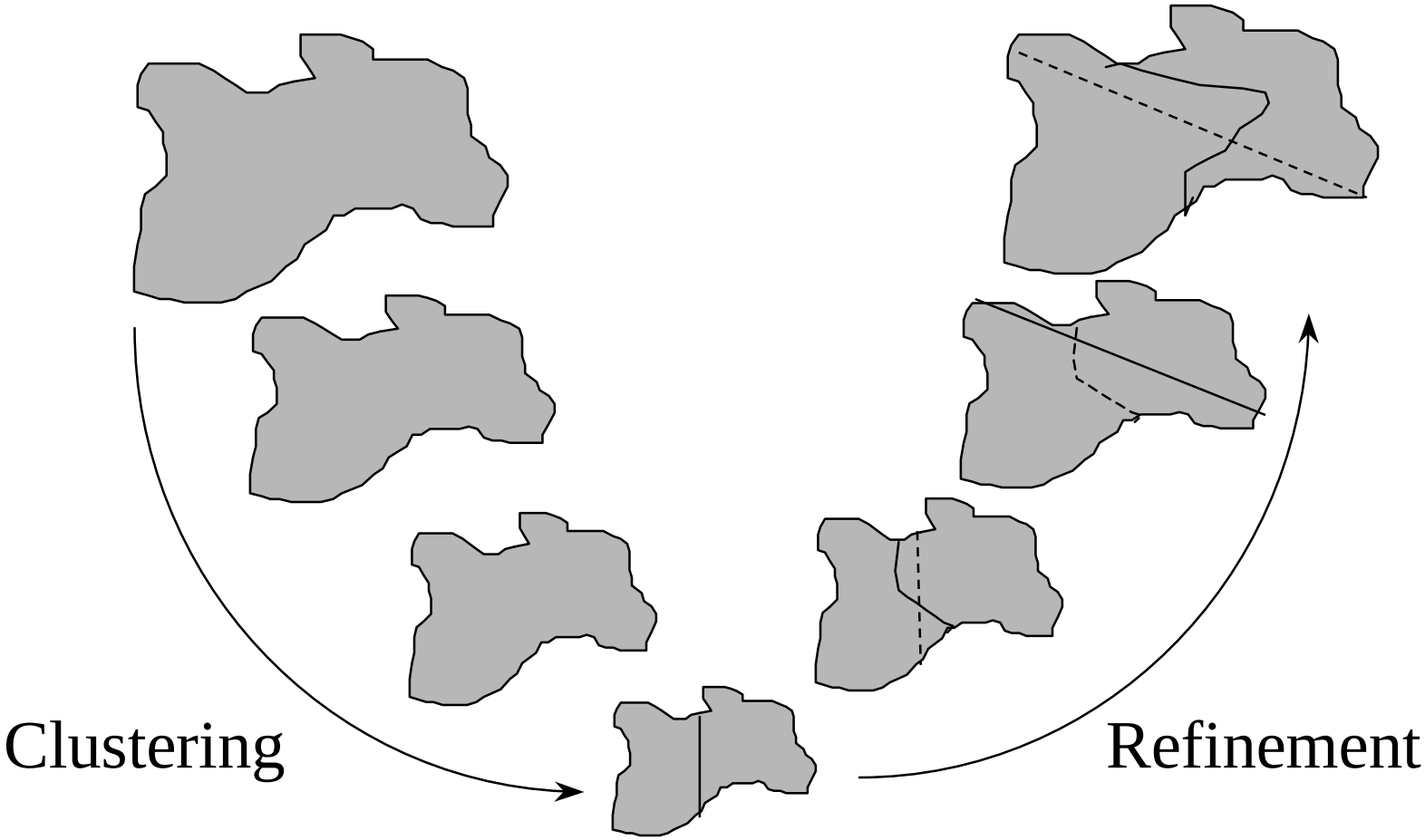


- Advantages: Simple, efficient and fast
- Disadvantage: Poor quality for large instances

Iterative Algorithms

- Folklore greedy shift, swap
- 1970 Kernighan-Lin
- 1982 Fiduccia-Mattheyses
- 1983 Metaheuristics… - GA, SA, LSMC
- 1984 Goldberg-Burstein, two-level
- 1989 Krishnamurthy, Sanchis,
- 1993 Quick Cut
- 1995 Metis, Chaco, … Multilevel

Multilevel Partitioning



Iterative Algorithms

- Folklore greedy shift, swap
- 1970 Kernighan-Lin
- 1982 Fiduccia-Mattheyses
- 1983 Metaheuristics… - GA, SA, LSMC
- 1984 Goldberg-Burstein, two-level
- 1989 Krishnamurthy, Sanchis,
- 1993 Quick Cut
- 1995 Metis, Chaco, … Multilevel
- 1996 PROP, CLIP, CDIP
- 1997 MLc, HMetis
- 1998 Deep Prop, ISPD98 suite

S. Dutt (UI-Chicago)
G. Karypis (U Minn)

Iterative Algorithms

Practicality/creativity:

- relaxed balance constraints
- multiple unlocks
- early termination
- dual representation
- V-cycles

Spectral / Geometric

- Hall70
  - closest legal partitioning to k smallest eigenvectors
- Barnes85, HagenK91, ChanSZ93
- Blanks85, FrankleK86, ArunR91, AlpertY95
- Ordering-based: 1-D place (order) then partition
- Embedding-based: legalization of analytic placement

Implications of Technology

- 1/DSM:
  - top-down hierarchical design synthesis, validation, reuse
  - RTL FP, wire planning
- DSM: spatial embedding matters
  - tighter links within, between design phases
  - analysis macromodels ≠ usable objectives

$\Rightarrow$ Prediction, Convergence

Combinatorial Algorithms

- Min-delay clustering (replication) LawlerLT69
- Network flows
  - cut
  - replication
- Mathematical programming
  - replication/retiming
  - constrained partitioning (MCM's)

C. K. Cheng (UCSD)
D. F. Wong (UT Austin)

Top-Down Design Context

- Prediction of achievable solutions
  - accurate “macromodels”
  - instance models and tool models
- Convergence
  - forward-annotation of constraints
  - forward-annotation of knowledge, design state
  - never forget, always cheat
- Two flavors of convergence
  - unifications
    (“analysis back plane”; “unified FP/ mapping/layout”)
  - methodology (“global iteration harmful”)

Spatial Embedding Context

- Effects must be understood earlier
- Fundamentally, is placement
- Many complexities
  - hard constraints
  - non-geometric objective function terms
  - non-local objective function terms
  - partial or incomplete data
  - heterogeneous/homogeneous, continuous/discrete phase transitions
  - hierarchy reconciliations

Mission Statement

"Partitioning facilitates the divide-and-conquer approach by decomposing problems in a manner appropriate to the application without losing too much solution quality."

- Partitioning objectives, algorithms should be fitted to applications
- Not other way around
- Example: row-based placer evolution

A Synthesis of Placer Evolution

- Top-down (partitioning) technology
  - top-down bisection = placement onto 2 points!
  - terminal propagation DunlopK85
  - quadrisection SuarisK87
  - quadrisection with exact placement objective HuangK97

  $\Rightarrow$ coarse-grain abstraction of layout region
  fine-grain netlist representation

A Synthesis of Placer Evolution

- Top-down (partitioning) technology
  ⇒ coarse-grain abstraction of layout region
  fine-grain netlist representation
- Flat (annealing) technology
  – (multilevel) clustering for speedup (Sechen)
  ⇒ coarse-grain netlist representation
  fine-grain abstraction of layout region

A Synthesis of Placer Evolution

- Top-down (partitioning) technology
  $\Rightarrow$ coarse-grain abstraction of layout region
  fine-grain netlist representation
- Flat (annealing) technology
  $\Rightarrow$ coarse-grain netlist representation
  fine-grain abstraction of layout region
- Critical observation: Coarsenings of netlist, layout abstraction are orthogonal and can be independently applied

Futures I - Prediction

- Prediction requires instance models
  - delay and temporal structure
  - communication and function complexity
  - enables design feasibility analysis
- Prediction requires tool models
  - what knobs matter?
  - BSF curves for iterative methods
  - order statistics for multistart metaheuristics

Futures II - Optimization Mindset

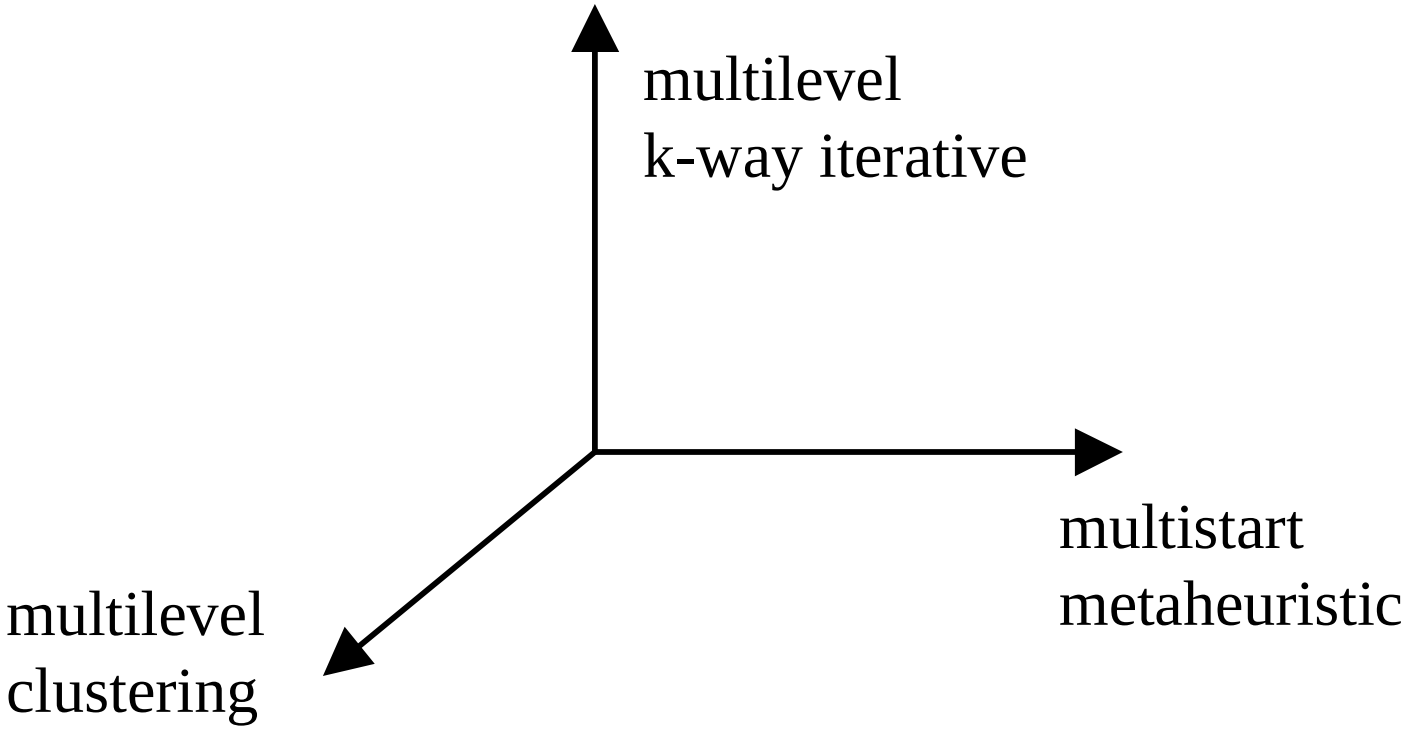
- Understand partitioning as resource-bounded discrete global optimization
- Combinatorial structure
  - phase transition between discrete packing, continuous min-cut
  - sensitivity of partitioners to this transition
- Divergence of objectives
  - HP (bbox) for placement; cut for partitioning
  - how to optimally interpolate “corrections”?

Futures III - Spatial

- Formulations that explicitly account for spatial embedding
  - floorplan-driven partitioning
  - embedding into prototyping architectures
  - some non-geometric objective function terms
- Bidirectional links between placement, partitioning
- Non-local objective function terms
  - path timing-driven partitioning

Futures IV - Limits

- Limits of multilevel FM for placement



Futures V - Clustering

- Improved understanding of clustering
- Purposes
  - reduce complexity
  - prevent mistakes
  - capture knowledge that would otherwise be unknowable
- Principled unification:
  - objectives that achieve specific goals
  - heuristics that optimize the objectives
  - measured progress w.r.t. goals, applications

Bottom Line

- Mission statement
- Spatial, methodology contexts
- Partitioning = optimization
- Key topic, many key open questions
- Need missionaries with right message

Panel

- Charles J. Alpert
  - Member of Technical Staff
    IBM Austin Research Laboratory
- George Janac
  - Chief Technologist
    Cadence DSM Business Unit
- John Lillis
  - Assistant Professor
    Univ. of Illinois at Chicago

Questions for the Panel

- Is clustering the key? Where is it useful?
- What are the most important formulations today? In 5 years?
- What are 2 open problems you'd like to see solved?
- Your questions!