Optimization in VLSI design, E2004
- Exercises for week four.

Jens Egeblad

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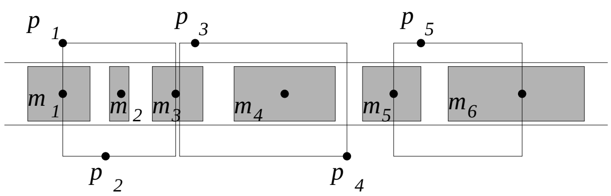
Exercise 1 - Optimal Single-Row Placement with Fixed Ordering (60 min.) (Partly Mandatory)

Consider the problem of placing standard-cell modules in a single row. They all have equal height. However, even minimizing the net-length in this restricted problem with only one row such the modules do not overlap, is an NP-Hard problem.

Fortunately, we can solve a slightly simpler problem. Assume that we know the optimal sequence of modules in advance. Let $m_1, \ldots, m_n$ be the list of modules. Let $x_1, \ldots, x_n$ be the x-coordinates of the modules and $w_1, \ldots, w_n$ the width of each module.

Now assume that some of the nets are connected to external/fixed pins: $p_1, \ldots, p_m$, with x-coordinates $x'_1, \ldots, x'_n$. Of course the pins' x-coordinates are fixed!

Example:



Here there are 6 modules, 5 fixed pins and 3 nets. All pins on modules are at the center of the modules. The three nets n_1, n_2 and n_3 connects as follows:

$$n_1 : m_1, m_2, m_3, p_1, p_2$$
$$n_2 : m_3, p_3, m_4, p_4$$
$$n_3 : m_5, m_6, p_5$$

We are considering the bounding box net-length so we wish to minimize the width of the bounding boxes of incident pins of each nets:

$$\sum_{n \in N} BB(n),$$

where $BB(n) = \max_{p \in p(n)} p_x - \min_{p \in p(n)} p_x$. Note that we only need to consider the x-direction since the y-direction is completely fixed. Note also that the set of pins $p(n)$ incident with each net n include pins at the center of connected modules.

Q1: Mandatory Is the placement on the figure optimal with this ordering? If not, how can you make an optimal solution?

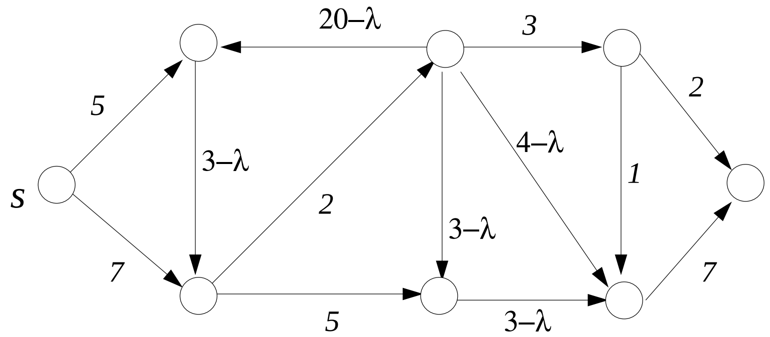
Q2: Mandatory Formulate this as a Linear Program (LP). Remember that ordering of modules is fixed, so m_i is completely left of m_j for $i < j$. Also try to keep (LP) as simple as possible, i.e. without needless constraints!

Q3: Dualize (LP).

Q4: Argue that the dual of (LP) is a flow or graph problem!

Exercise 2 - Parametric Shortest Paths (30 min).

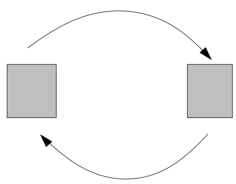
Consider the following Parametric Shortest Path Problem:



Q5: Find all λ-values and shortest path trees for this graph.

Exercise 3 - Tricycle Local Search Neighborhood (30 min).

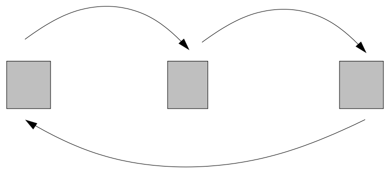
If we assume all modules are of equal size, a a good local search neighborhood may be defined by a swap of the position of two modules m_1 and m_2:



Assume that we minimize the bounding-box net-length and in fact only the x-part of it.

Q6: Can you come up with an example where a swap of two modules will *improve* the bounding-box net-length?

Of course proceeding iteratively and greedily by swapping modules from some initial solution does not in general produce the optimal solution. Therefore one might consider the neighborhood where three modules m_1, m_2 and m_3 are interchanged:



So m_1 is placed at m_2's old position, m_2 at m_3's and m_3 at m_1's old position.

Q7: Can you come up with an example where an interchange of three modules in this fashion improves the bounding-box net-length, but such that the interchange could *not* have been done by two succeeding improving *swap*-moves? In other words do tricycle-moves allow us to move to solutions that swap-moves do not?

Exercise 4 - Design a Final Placement Heuristic (30 min.) (Mandatory)

Based on the exercises you have done this week and the last weeks as well as the final-placement heuristics demonstrated at the lectures, can you come up with a final placement heuristic of your own?

Q8: What is your approach to the Final Placement Problem? (Sketch)

Help: You may keep everything simple. So you can consider e.g. only the standard-cell problem where modules must be placed in rows and all modules have equal height. In fact, since the single row-problem is also NP-hard, you may even just consider the problem where only one row needs to be optimized.