Extended abstract

Placement problems are of high practical value. Normally, they are computationally expensive and largely require heuristic approaches. One of the methods is based on force-directed models.

We aim at construction of dynamical systems, evolution and properties of which can be interpreted in terms of common placement objectives. Similar to the formalism of classical mechanics, an adequate dynamical description will make it possible evaluating certain solution characteristics before entering computationally expensive experimental phases.

Modeling placement with minimal area objective, we consider circular particles of different sizes. When sufficiently separated, they attract each other according to Newton’s Law of gravity. In spatially close pairs, however, the interaction flips its sign. The governing equations are iteratively integrated by the 4th-order Runge-Kutta method. In order to localize the motion, we also enforce absolutely inelastic rebounds from the configuration boundaries.

Testing results show that in the state of minimal energy smaller particles are pushed towards the center of masses and larger ones are aligned along the boundaries. The developed dynamics naturally suggests an iterative mechanism of reshuffling and packing, which essentially reduces the negative influence of initial conditions.

The approach is also applied to a placement model with minimal wire length requirement. It is shown that randomly generated initial configurations of connected particles are untangled by the acting forces.

The achieved results suggest future work in two directions – application of the method to practical placement problems and its adaptation as a pre-preprocessing tool for preparation of higher-quality initial conditions for other algorithms.

Systems of Interacting Particles as Placement Models

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Abstract – We look at placement problems from dynamics point of view and construct systems of interacting particles, evolution of which can be interpreted in terms of common placement objectives. Similar to the formalism of classical mechanics, a good dynamical description may evaluate certain characteristics even before entering computationally expensive experimental phases. We demonstrate performance of the constructed models and discuss their properties.

Keywords – placement, model, optimal configuration, force, dynamical systems, interacting particles, numerical integration.

I. Introduction

Placement and floorplanning problems have been widely studied for long time because of their high practical value. Together with wire routing, components placement is the main procedure in VLSI circuits [1] and design of printed circuit boards [2]. Packing and cutting problems arise in many industrial branches, while placing items in a container. 2D packing algorithms are surveyed in [3]. Normally, placement problems are computationally expensive and largely require heuristic approaches.

One of the methods is based on force-directed models introduced in early 70s [4]. The components are treated as interacting bodies and their eventual locations are determined based on the governing dynamics. Some examples include a maze router algorithm with force-directed star placement [5]; an efficient finer time force-directed algorithm for 3D cell placement [1]; positioning of vertices in large-scale graphs, where force-directed approach significantly prevails over other methods [6].

We aim at construction of dynamical systems, evolution and properties of which can be interpreted in terms of common placement objectives. Similar to the well developed formalism of classical mechanics [7], an adequate dynamical description may allow evaluating certain characteristics of solutions before entering computationally expensive experimental phases.

II. Compact Configuration Model

In order to model 2D placement with minimal area objective, let us consider N circular particles of different sizes to appear in a compact configuration permitting minor overlapping. For simplicity, the measure of compactness is the configuration boundaries – an upright rectangle circumscribing all the particles. When sufficiently separated, they attract each other according to Newton’s Law of gravity with masses proportional to the radii. In spatially close pairs, however, the interaction...
flips its sign. The governing equations to be iteratively integrated by the 4th-order Runge-Kutta method appear as:

\[
\begin{align*}
\frac{d^2 x_i(t)}{dt^2} &= \sum_{i'k} \delta_{ik} F_{x}(x_i', x_i, d_{ik}), \\
\frac{d^2 y_i(t)}{dt^2} &= \sum_{i'k} \delta_{ik} F_{y}(y_i', y_i, d_{ik}),
\end{align*}
\]  

(1)

where \( F_{x} \) and \( F_{y} \) are Cartesian components of Newton’s force \( F(i, k) = r_i r_k / d_{ik}^2; d_{ik} = ((x_i - x_k)^2 + (y_i - y_k)^2)^{1/2} \). The force sign is defined by

\[
\delta_{ik} = \text{signum}(d_{ik} - \alpha (r_i + r_k)),
\]

(2)

where \( \alpha \approx 2 \) is determined experimentally, as to balance between gaps and overlaps.

In order to localize the motion, we recalculate the configuration area and, if increased compared to the previous iteration, assign zero velocity to all particles. Effectively, we enforce absolutely inelastic rebounds from the configuration boundaries.

Certain peculiarities have been observed in evolution of randomly generated particles of different sizes. Initially, under the influence of the attractive forces, the particles move towards the center of masses. When sufficiently packed, repelling forces appear and gradually expand the configuration. The particles oscillate around the local equilibrium state until enough space is created for abrupt reshuffling and move of smaller particles towards the center. For \( N \gg 1 \) the eventual steady-state configuration is practically spherically symmetric. In case of \( N < 100 \), the largest particles are aligned along the configuration boundaries with interior filled by the smaller ones.

The observed behaviour becomes more apparent and smoother, if the parameters \( \delta_k \) are assigned magnitudes:

\[
\delta_k = d_{ik} - \alpha (r_i + r_k),
\]

(3)

In order to proceed with stable integration in this case, the time step should be decreased by an order of magnitude. The whole dynamics is visualized by plotting the dimensionless configuration area against the number of interactions in Fig. 1.

The area is shown in units of the total area of particles, and local minima indicate the reshuffling events.

### III. Connected Configuration Model

In many applications the minimal area requirement plays secondary role. In circuit design, for example, minimal wire lengths is a common primary constraint. As above, let us consider \( N \) circular particles, some of which are connected. The objective is to arrange them as to minimize the total connection lengths.

In order to include connections in the model of Eqs. (1) and (2), we modify the forces: \( F(i, k) = r_i r_k \), if the \( i \)-th and \( k \)-th particles are connected, and \( F(i, k) = r_i r_k / d_{ik}^2 \) otherwise. Fig. 2 shows evolution from a random initial state towards a topologically optimal configuration.

It is interesting to mention, that the smoother dynamics according to Eq. (3) cannot untangle the configuration under the adopted damping mechanism.

### Conclusion

Hook’s Law is a popular choice for modeling the forces in placement algorithms [4] and [5]. Contrary to that, we look at analogy with Newton’s Law of gravity as to maximize the close-range interaction, since the core interaction between the particles occur in their mutual vicinity. Testing results show that in the state of minimal energy smaller particles are pushed towards the center of masses and larger ones are aligned along the boundaries.

Despite their popularity, force-directed algorithms exhibit certain drawbacks. Particularly, quality of the initial conditions influences the final configuration [8]. The dynamics of our placement models naturally suggests an iterative mechanism of reshuffling and packing, which essentially reduces the negative influence of initial conditions. Therefore, in addition to direct applications to placement problems, the approach can be used as a pre-processing tool in preparation of better initial conditions.

### References


