Pseudotriangulations and Rigidity

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1. Pseudo-Triangulating

Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add edges...
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add one edge
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add two edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add three edges
Start with a point set... form the convex hull
10 vertices: 2 \cdot 10 - 3 degrees of freedom

Add four edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add five edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add six edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add seven edges
Start with a point set... form the convex hull
10 vertices: 2 · 10 − 3 degrees of freedom
Add eight edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add nine edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add ten edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add eleven edges
Start with a point set... form the convex hull
10 vertices: $2 \cdot 10 - 3$ degrees of freedom

Add twelve edges - *Pseudo-Triangulation*
2. Properties

Theorem 1 (Streinu - 2000)

The following are equivalent

- $G$ is a pseudo-triangulation with the minimum number of edges.
- $G$ is a pointed pseudo-triangulation
- $G$ is a pseudo-triangulation with exactly $2n - 3$ edges
- $G$ is non-crossing, pointed, and has $2n - 3$ edges
- $G$ is non-crossing, pointed, and maximal with this property
Corollary 1 If any of the above conditions are satisfied, then $G$ is generically minimally rigid in the plane and any realization of $G$ as a pseudo-triangulation is 1st order rigid.

Theorem 2 Every planar graph which is generically minimally rigid has a realization as a pointed pseudo-triangulation.

Proof 1 uses an inductive construction together with topological information.

Proof 2 uses linear algebra - Tutte’s approach to drawing a graph.
3. **Definition of CPPT**

A *combinatorial pointed pseudo-triangulation* (cppt) is an assignment of labels, *big* and *small*, to the angles of a plane graph such that

- every vertex has exactly one big angle,
- every interior face as exactly three small angles
- the outside face has only big angles.

\[ G \] has

- \(-n\) vertices,
- \(-e\) edges and
- \(-f\) faces.

Necessary condition for the existence of a cppt:

\[ e = 2n - 3 \]

\(\text{(Since } n - e + f = 2 \text{ and } 3f - 3 + n = 2e.)\)
4. Combinatorial CPPT

A graph in the plane
A combinatorial pseudo-triangulation
A topological realization
5. Examples

A Combinatorial Pseudotriangulation
Orient edges away from the pointed vertex
Delete all non-oriented edges
Triangulate the pseudotriangles
Start again
Add combinatorial angles
Orient away from the large angles.
Form $G^*$
convexify
Back to $G$. 
6. Directed Tutte method

Theorem 3 From every interior vertex of $G^*$ there are three vertex disjoint paths to the boundary, consequently $G^*$ can be drawn with straight non-crossing lines in the plane in such a way that a given positive stress on all directed edges is resolved.
7. Schnyder trees.
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\[ G^*_2 \]
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Some Examples:

\begin{itemize}
\item \textbf{Directed Tutte method}
\item \textbf{Schnyder trees.}
\end{itemize}

\[ \begin{align*}
G_2^* & \quad \text{Directed graph}\n\end{align*} \]
8. A bad example
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Reciprocal Figures

Some Examples:
10. Reciprocal Figures

We want to draw the geometric dual using the same edge directions.

Construction

Use a framework with a resolvable stress, non-zero on every edge, for example a cycle in the rigidity matroid. Such a cycle corresponds to a pseudo-triangulation with one non-pointed vertex.
Theorem 4 If a generic 2-cycle is realized as a pseudo-triangulation, then the reciprocal diagram is also a pseudo-triangulation.
Lemma 1 There is, up to rotation, a one to one correspondence between the set of pseudo-triangles $T$ and the set of PTC cells, $C(T)$, such that the vector paths between the distinguished vertices on the boundary of $C(T)$ are translations and half-turns of the pseudo-arcs of $T$. 
proof
Lemma 2 Given a framework, together with a resolvable stress $s$ and a pseudo-triangle $T$. Suppose that $T$ is a face in the rotation system which governs the reciprocal. The following are equivalent:

1. The cyclic ordering around the reciprocal vertex is the reverse of the cyclic ordering around $T$.
2. The reciprocal figure is pointed at the vertex corresponding to $T$.
3. There is exactly one improper sign change on the stresses as one reads around $T$.
11. Some Examples:
Seven Wheel 1:
Seven Wheel 2:
Center segment revolves:

Graph not in a plane embedding.
Center segment revolves and rotates:

Graph not in a plane embedding.
A non-planar reciprocal: