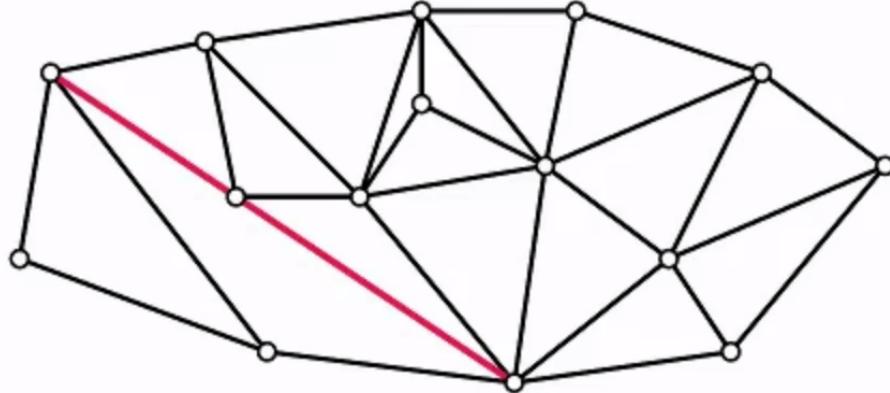


Triangel

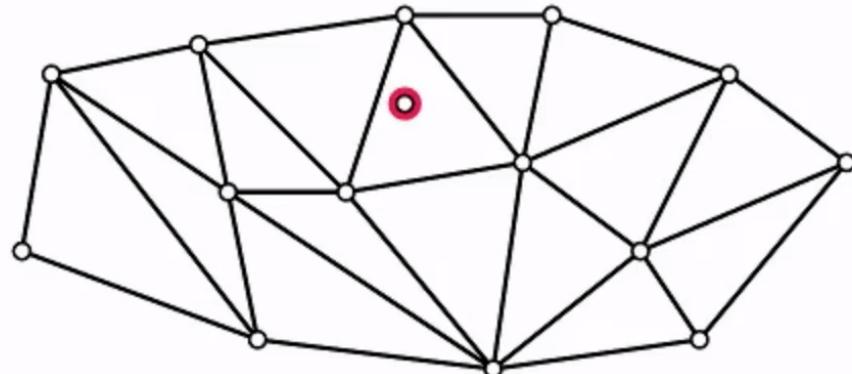
- simplest piece of surface
- allow modelling surfaces
- important for Computer Graphics

Triangulation of Point Set S

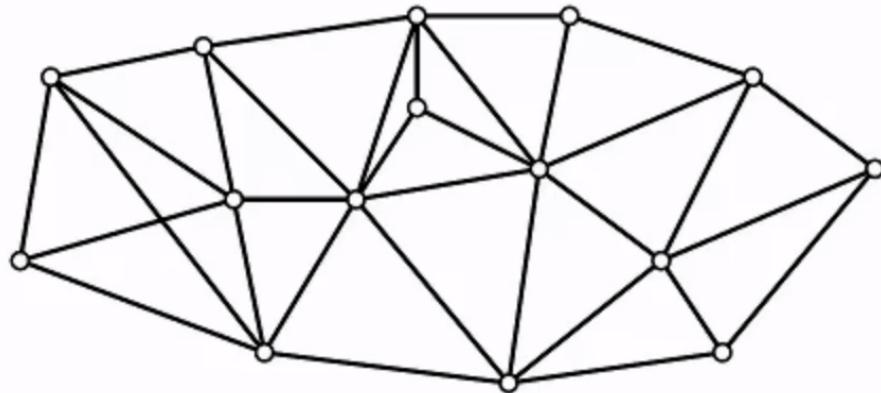
- [[Convex Hull]] partitioned into interior-disjoint triangles
- no point of S inside a segment or triangle



Not a triangulation of S . **Why?**

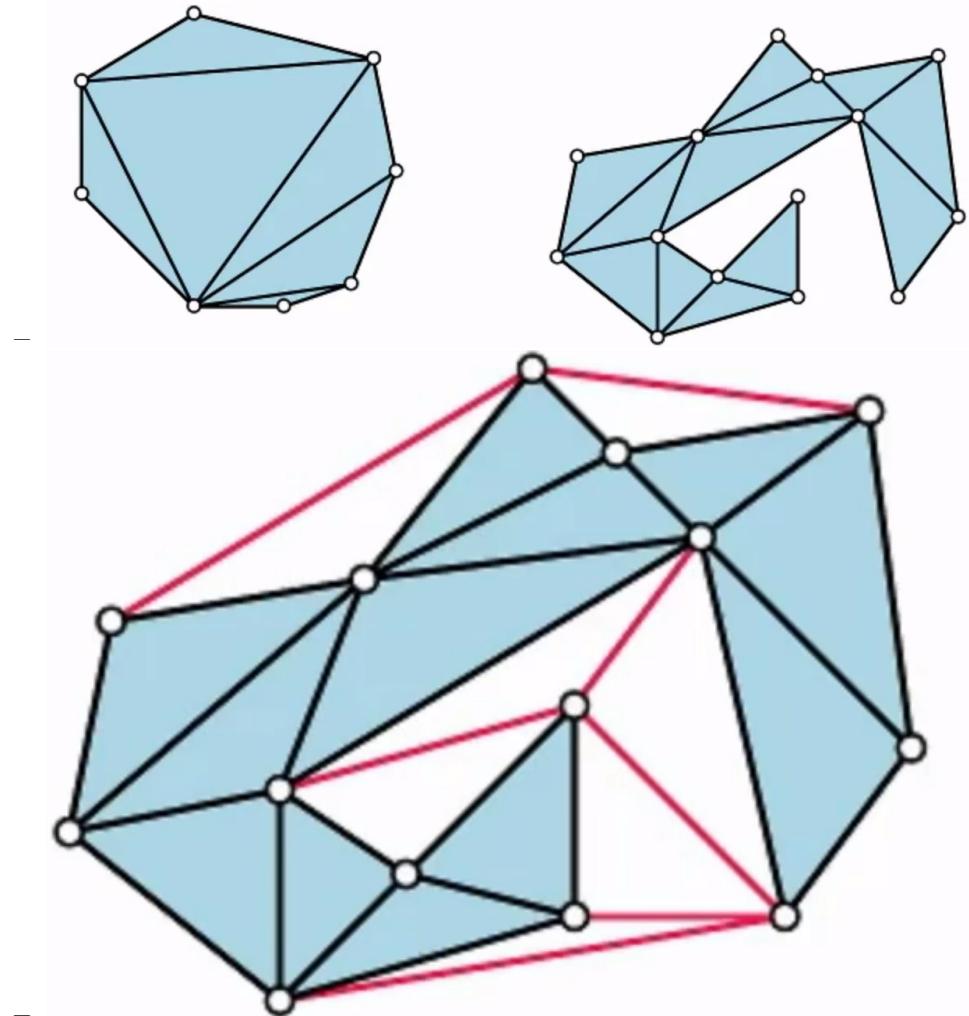


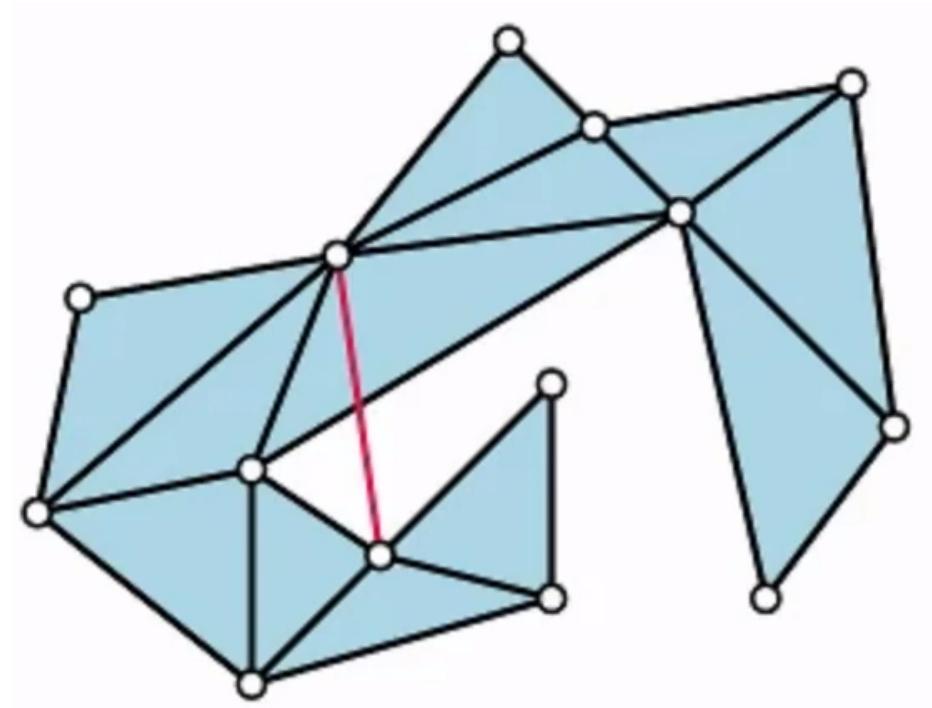
Not a triangulation of S . **Why?**



Triangulation of Polygon P

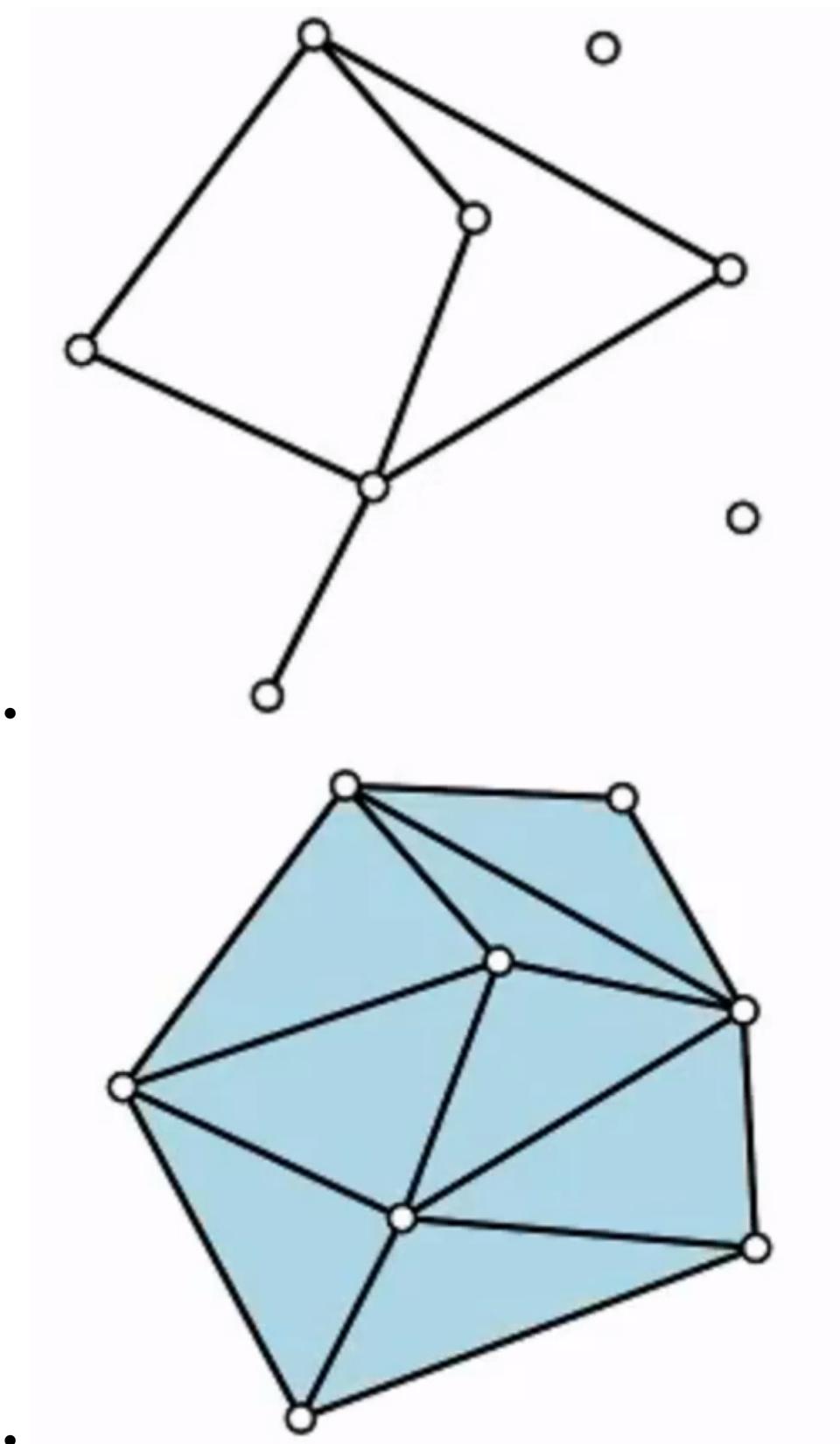
- polygon P with vertex set S partitioned into interior-disjoint triangles
- no point of S inside a segment (or triangle)





Maximal Plane Straight-Line Graphs

- Given a plane straight-line graph
- We add edges as long as we can.
- The result is a triangulation.
- The same can be done for polygons / polygonal regions.



Elements of Triangulation

- A triangulation consists of vertices, **edges**, and **triangles**.

- number of edges and triangles depend on number of extreme points h of S

⇒ If S has h extreme points:

- $e = 3n - 3 - h$ edges
- $t = 2n - 2 - h$ triangles

Question: What about polygons with n vertices?

- $e = 2n - 3$ edges
 - $t = n - 2$ triangles
-

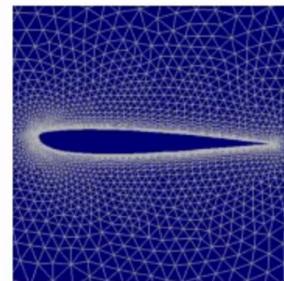
Applications

- Graphics/GIS

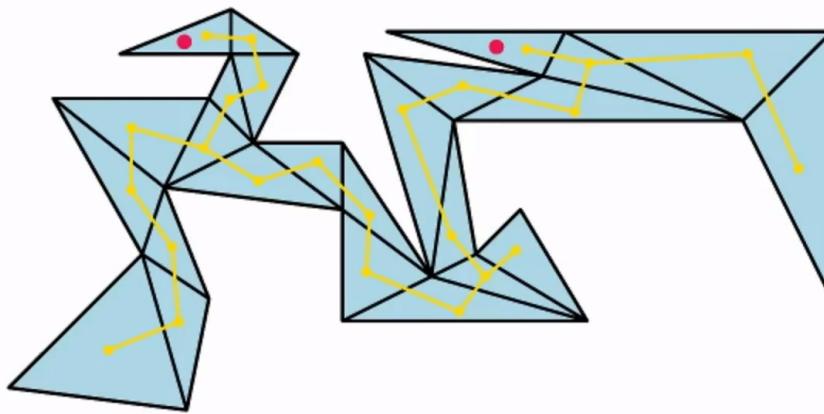
- The height of a terrain is measured at certain points.
- The points in a triangulation are elevated.
- An approximation of the terrain is obtained.
- Surfaces in 3D are modeled using meshes.
- Every element is a triangle
 - allows fast processing by graphics hardware
 - no checks necessary

- FEM

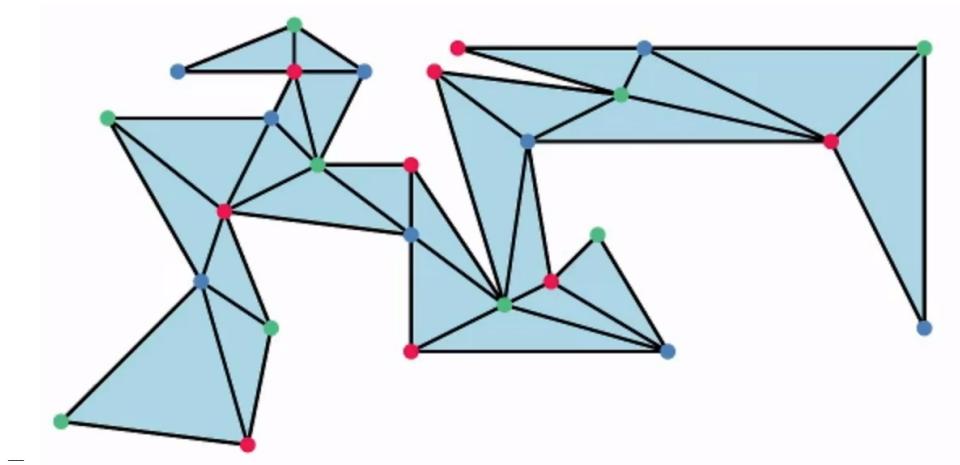
- Technique to numerically solve partial differential equations or integral equations.
- Approximated by a triangular mesh.
- Finite number of elements (usually triangles) give piecewise linear function.
- Numerically stable approximations need good meshes.
- Used, e.g., to analyze heat flow or forces in materials, or simulating fluid flows.



- geometric algorithms
 - Example: Shortest Path inside a polygon.
 - Also used in proving time bounds.
 - Example: Guarding

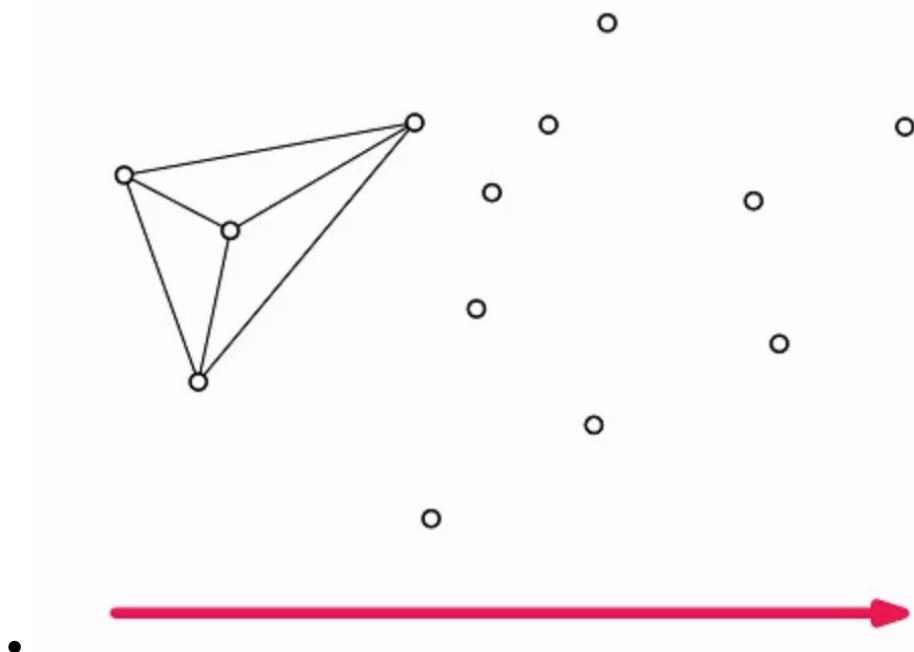


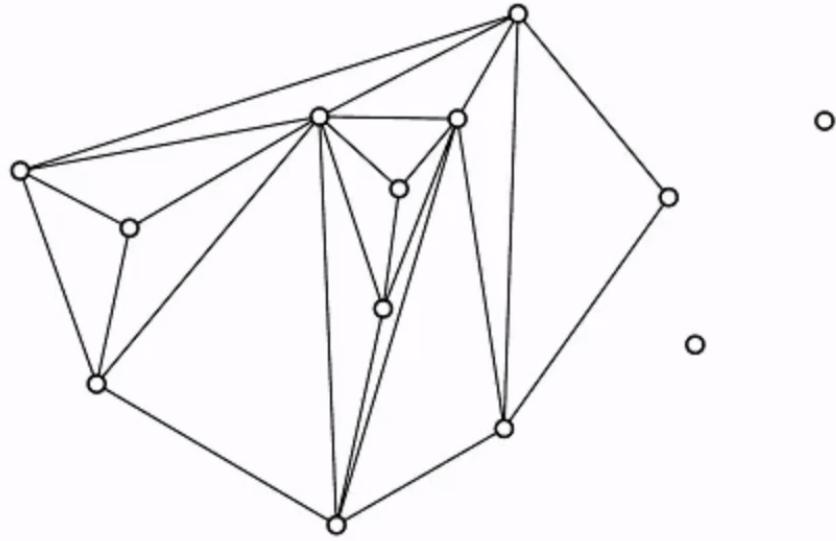
- [[Kombinatorik]]
 - neighbours have different colors



Canonical Triangulation

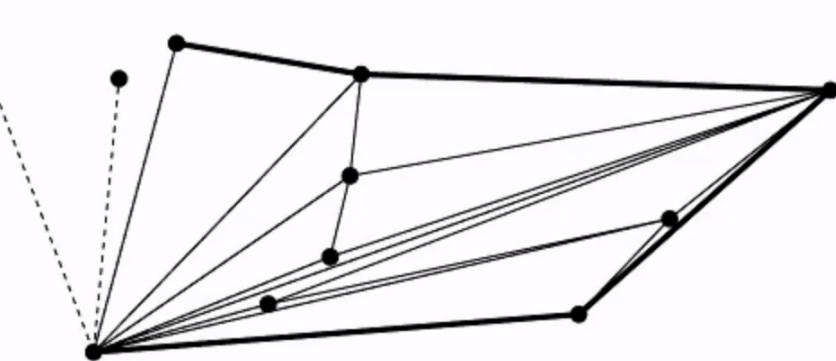
- combine 3 leftmost points
- add each point sequentially
 - combine this point with each point to the left which it still “sees”





• Triangulation with Graham Scan

- similar to creating [[Convex Hull]]
 - add edges to anchor point and to last convex hull vertex
 - don't remove edges



• Input:

- Array $p[1..N]$ of points ($N \geq 3$)

Output:

- Array q with convex hull vertices (in order)
- Stack t with triangulation edges

Preparation:

- Place the point with smallest y -coordinate into $p[1]$
- Sort all other points counterclockwise around $p[1]$:
 $p[i]$ is larger than $p[j]$ if $p[i]$ is left of the directed line from $p[1]$ to $p[j]$
- $p[1]$ and $p[2]$ are the first two convex hull vertices:
 Add them in this order to q , add $(p[1], p[2])$ to t .

```

for (i = 2 to N)
    if (p[i].y < p[1].y)    swap(p[1], p[i])
    sort p[2..N] counterclockwise around p[1]
    q[1] = p[1], q[2] = p[2], h = 2
    t.push((p[1],p[2]))

```

Process the remaining points from p[3] to p[N].

Processing point p[i]:

- Add (p[1],p[i]) and (p[i-1],p[i]) to t
- While from the last edge of the convex hull there is no left turn to p[i]:
 - remove the last point from q.
 - add an edge from p[i], to the last vertex in q to t.
- Add p[i] to q.

End:

- After p[N] has been processed, the convex hull vertices are stored in order in q and the triangulation edges are stored in t.

```

for (i = 3 to N)
    t.push((p[1],p[i]))
    t.push((p[i-1],p[i])) /* p[i-1] == q[h] */
    while (h>1 and not lefturn(q[h-1],q[h],p[i]))
        h = h - 1
        t.push((p[i],q[h]))
    h = h + 1
    q[h]= p[i]

```

- time complexity
 - Preparation in $O(n \log n)$ time due to sorting.
 - Building the triangulation: $\Theta(n)$ time. Why?

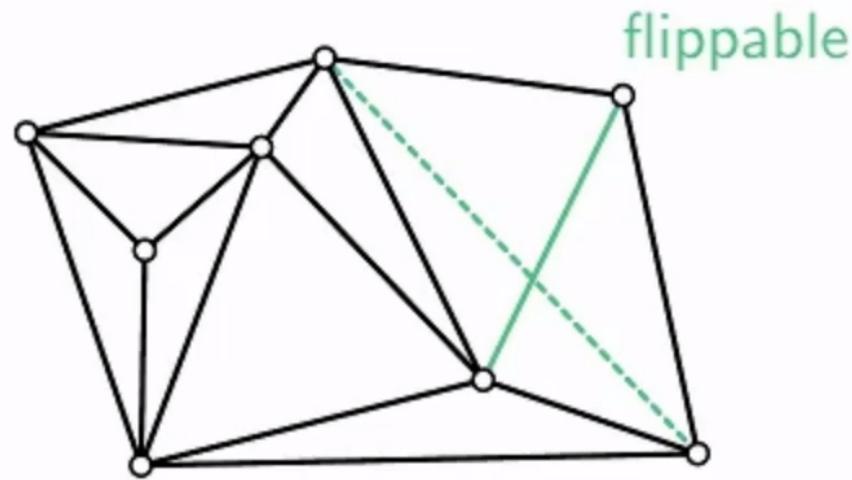
→ in total $O(n \log n)$ time.

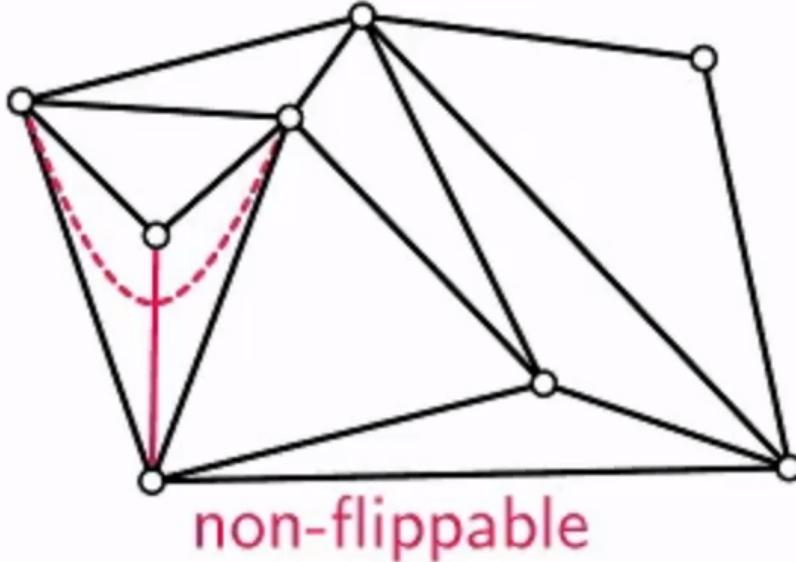
- space complexity
 - $O(n)$ in addition to input. Why?
- correctness

- After processing $p[3]$, we have a triangle.
 - Assume that before the round for $p[i]$, $i \geq 4$, t contains all edges of a triangulation for $p[1..i-1]$
 - In the round for $p[i]$, we add edges between $p[i]$ and all points of the convex hull of $p[1..i-1]$ that $p[i]$ “sees” \Rightarrow “fan” of triangles from $p[i]$ to extreme points, no edge crosses the convex hull of $p[1..i-1]$.
- \Rightarrow After the round for $p[i]$, t contains all edges of a triangulation for $p[1..i]$.
- \Rightarrow After the round for $p[N]$, t contains all edges of a triangulation for $p[1..N]$.
-

Local Transformation

- rebuild existing triangulation to different triangulation
- edge flips

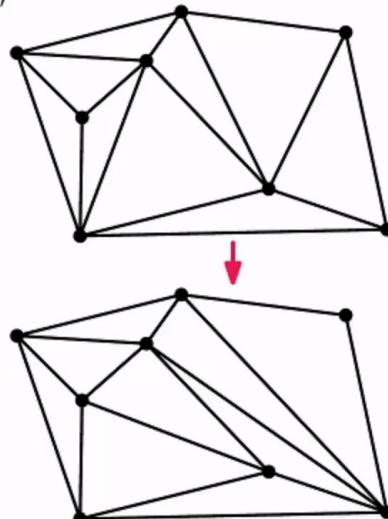




- useful for optimization in heuristics

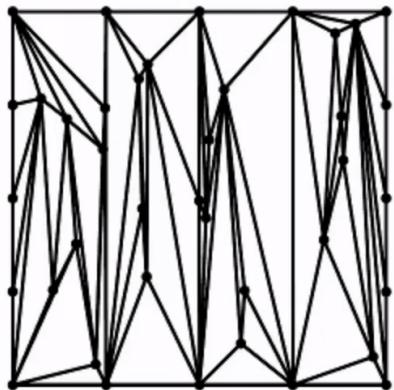
Flip Distance Problem

- Given:** two triangulations T, T' of a point set.
- Goal:** transform T into T' by subsequently *flipping* one edge at a time.
- Any triangulation can be transformed into any other by $O(n^2)$ flips (tight).
- Question:** what is the minimum number of flips needed, the *flip distance*?
- Determining flip distance is NP-complete.

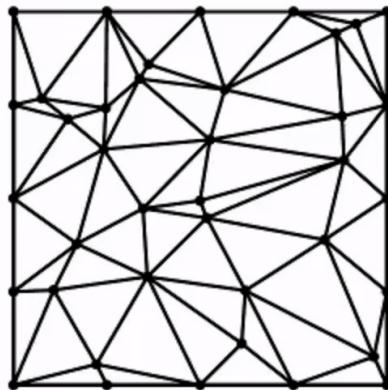


Delaunay Triangulation

Two copies of the same point set ...



Canonical triangulation



Delaunay triangulation

- Useful in practice and theory: Delaunay triangulation
 - obtainable by simple flip rules
 - optimizes several criteria
 - dual to the Voronoi diagram