

Efficient Triangulation for P2P Networked Virtual Environments



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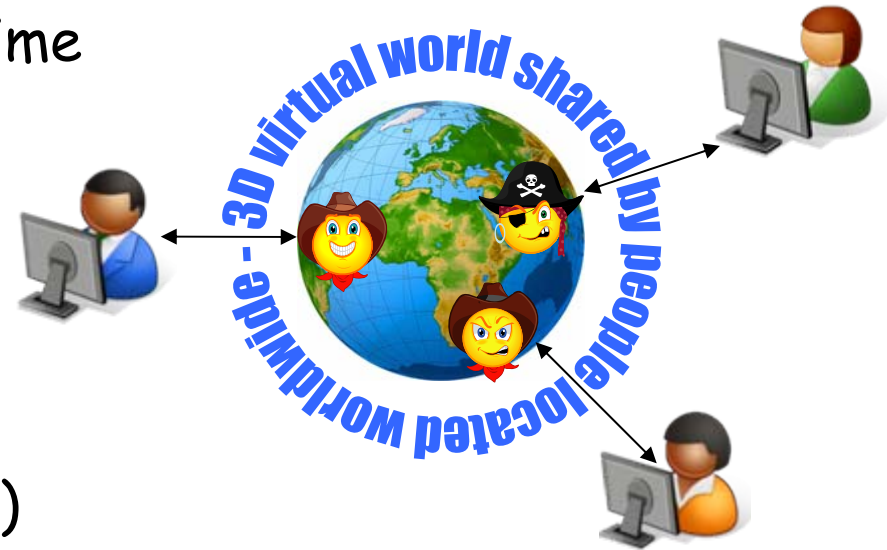


Networked Virtual Environment



□ Features

- A way of communication & interaction
- Immersion in a synthetic world through **avatars**
- Perceived shared space & time



□ Applications

- Military training (since 80's)
- Remote teaching & education, online meetings, ...
- **M**assively **M**ultiplayer **O**nline **G**ames (MMOGs)

NVEs : Current state



- ❑ Multi-billion dollar industry
- ❑ Growing number of subscribers
 - **10 million** subscribers for *World of Warcraft* (WoW)
 - **800,000** concurrent players for *WoW Burning Crusade*
- ❑ However...
 - \leq **5000** concurrent players per world
 - Why & How to scale ?

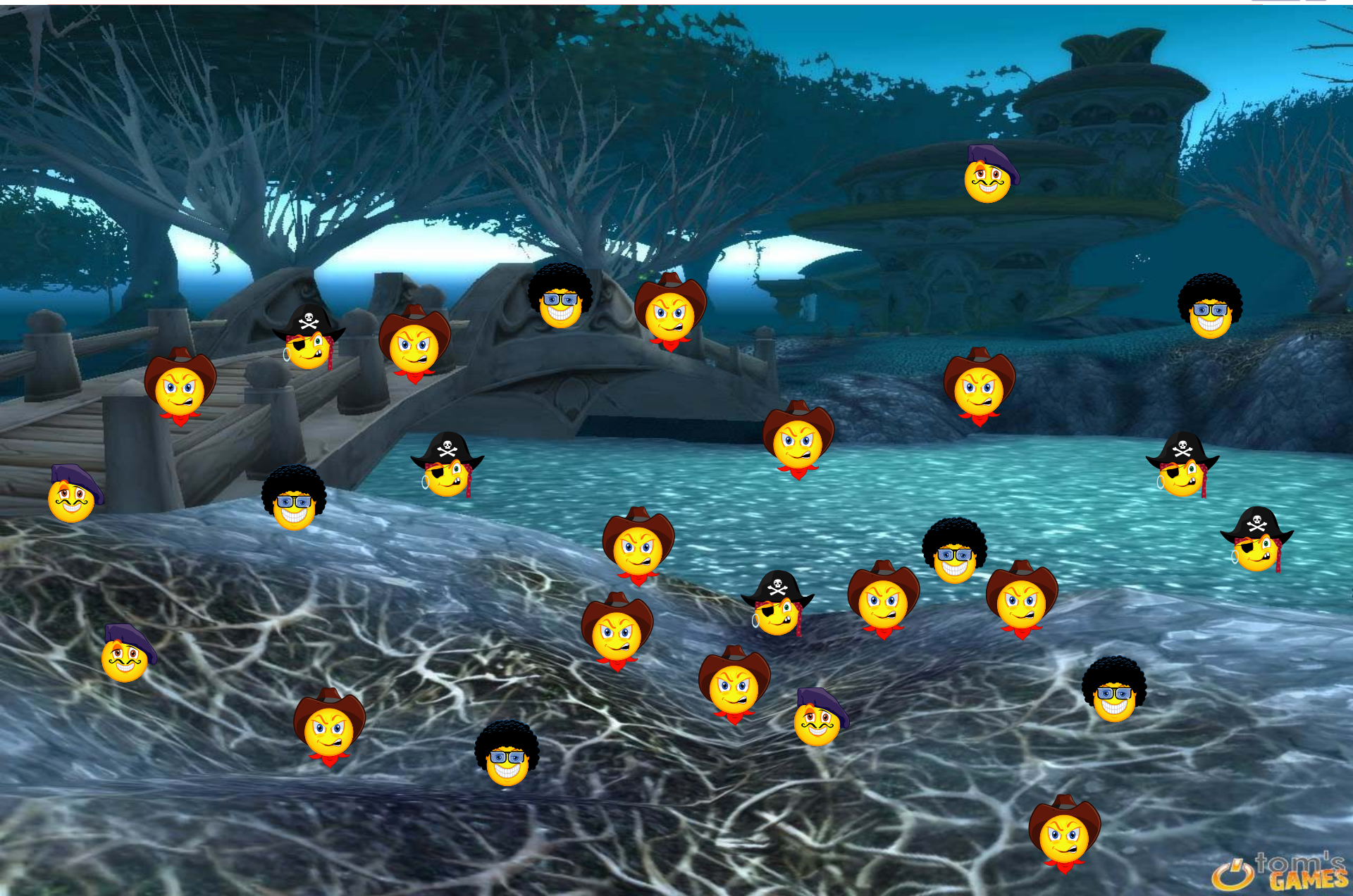
Towards a 3D WEB ?



Ultimately...

Can we have **all** users concurrently share one huge, realistic, and immersive virtual world ?

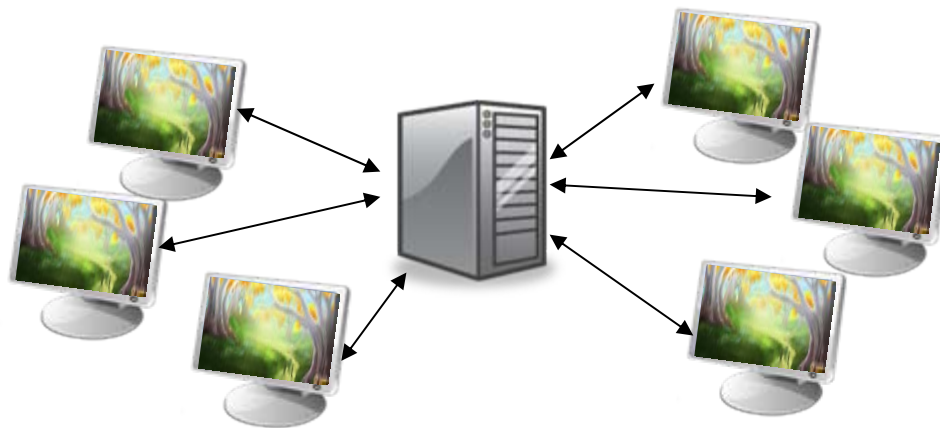
The scalability issue



System Models for NVEs (1)



Early stage : **Client/server**

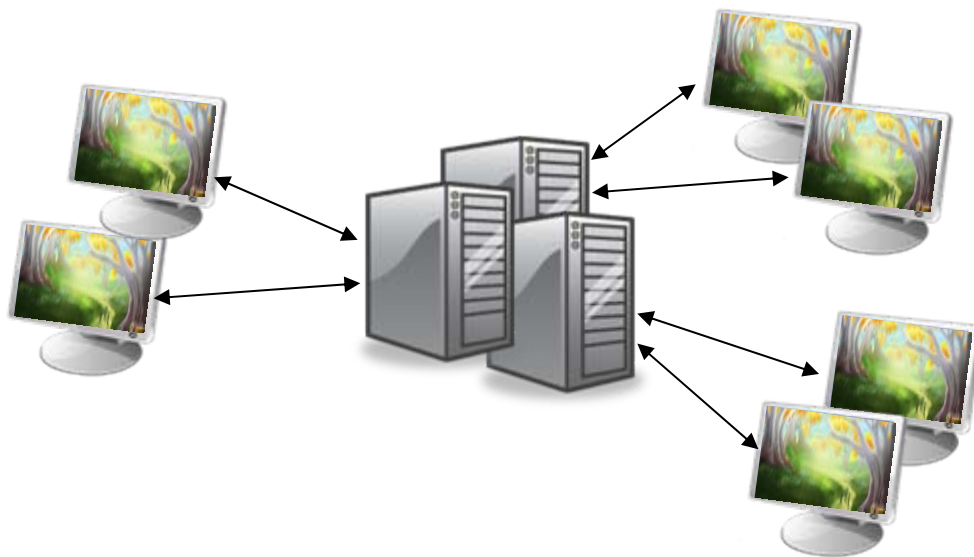


- ✗ **Server represents...**
 - ✗ a bottleneck
 - ✗ a single point of failure
- ✗ **Does NOT scale**

System Models for NVEs (2)



Current deployments: **server cluster**

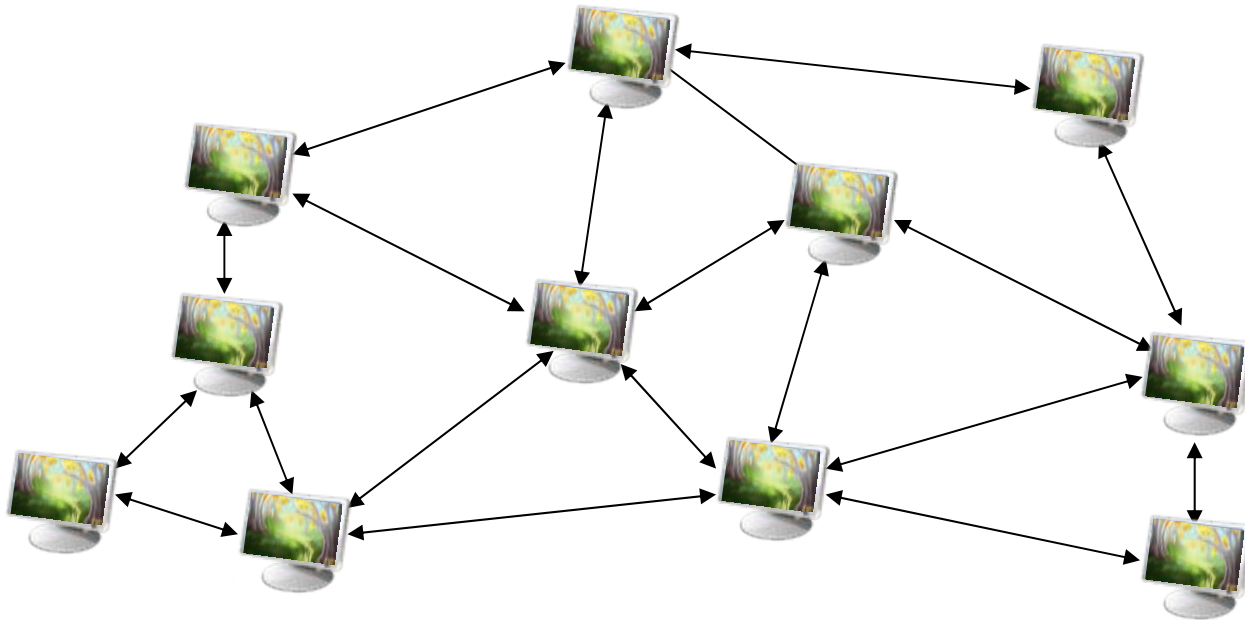


- × Expensive
- × Limited scalability
- × Crowding problems

System Models for NVEs (3)



P2P as a promising technology



- ✓ Highly scalable
- ✓ Cost effective

P2P challenges and Issues



❑ Overlay topology structuring

- Arbitrary
- Application semantics-oriented

neighborhood relationships

❑ Dynamic topology maintenance

- Users' join/leave
- Users' **continuous** movement in NVEs

neighbor discovery
&
self reorganization

❑ Distributed content management

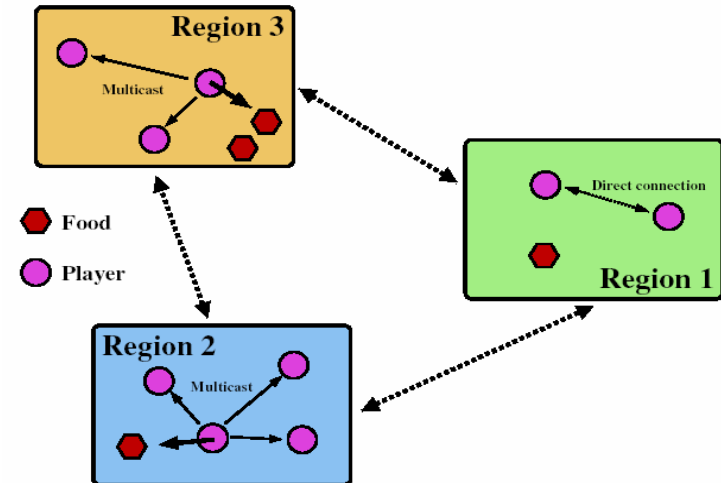
Related Works (1)

❑ SimMUD [Knutsson et al. 2004]

- Region-based
- Pastry/Scribe-based
- Multicast groups

- ✗ Fixed-size regions
- ✗ Coordinator-based
- ✗ Message relay

Performance & scalability problems



Source: [Knutsson et al. 2004]

❑ [Iimura et al. 2004]

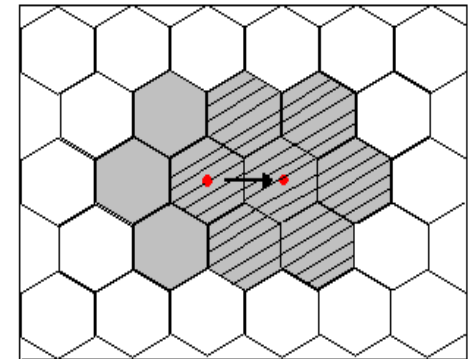
- Similar w/ no message relay

Related Works (2)



- [Kawahara et al. 2004]
 - Connection to closest neighbors
 - Regular neighbor list exchange
 - ✗ High communication cost

- **MOPAR** [Yu et al. 2005]
 - Hexagonal cells
 - 1 master/cell
 - Regular master neighbor list exchange
 - ✗ High communication cost



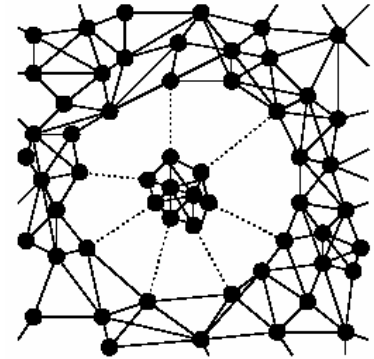
Source: [Yu et al. 2005]

Related Works (3)



❑ Solipsis [Keller et al. 2003]

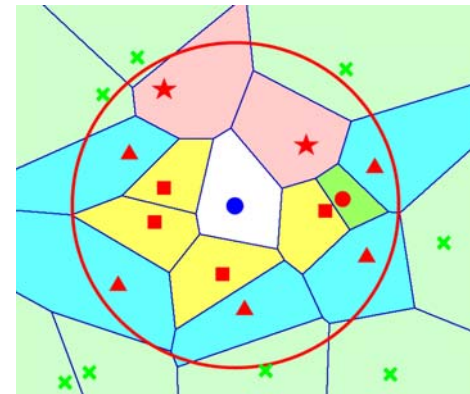
- Connections to **all** AOI neighbors
- Mutual cooperation for neighbor discovery
- ✗ Incomplete neighbor discovery
- ✗ Possible inconsistent topology
- ✗ Crowding issues => **high communication cost**



Source: [Keller et al. 2003]

❑ VON [Hu et al. 2004]

- Voronoi-based
- Connection to **all** AOI neighbors
- Mutual cooperation for neighbor discovery
- ✗ Crowding issues => **high communication cost**
- ✗ **High overlay maintenance cost**



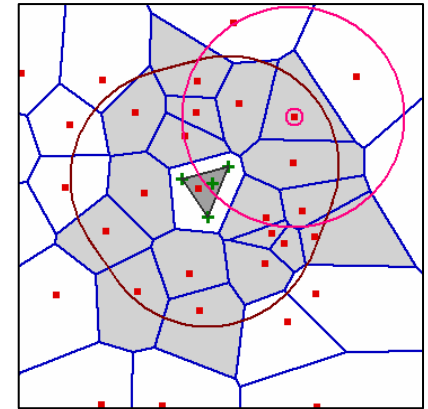
Source: [Hu et al. 2004]

Related Works (4)



❑ **VSM** [Hu et al. 2008], [Buyukkaya et al. 2008]

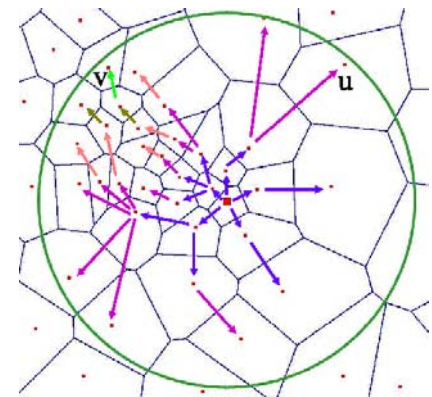
- VON-based
- Distributed state management
- ✗ Crowding issues => **high communication cost**
- ✗ **High overlay maintenance cost**



Source : [Buyukkaya et al. 2008]

❑ **VoroCAST** [Hu et al. 2008]

- VON-based
- Multicast within AOI
- Reduced bandwidth consumption per node
- ✗ Higher latency
- ✗ **High overlay maintenance cost**



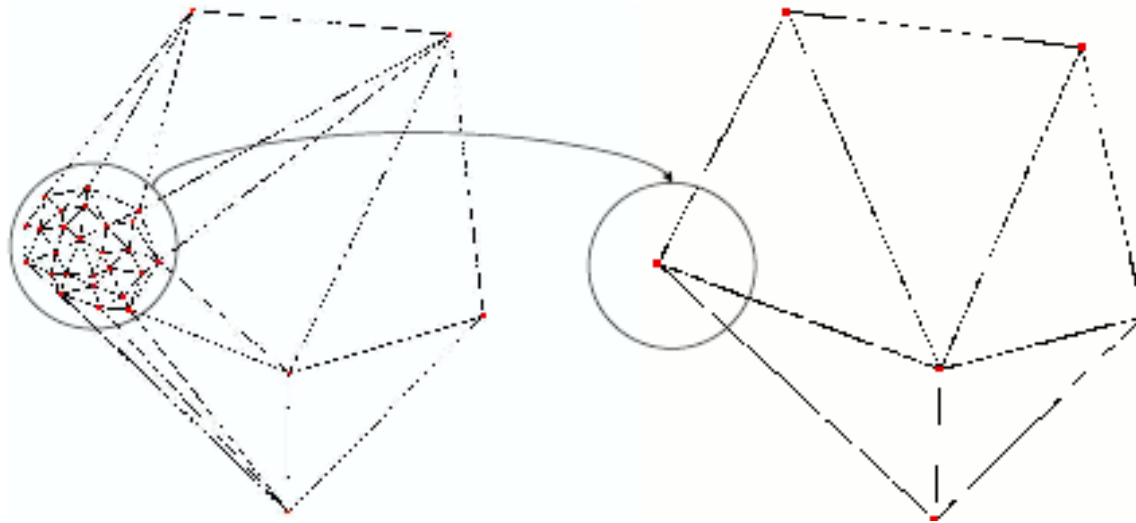
Source : [Hu et al. 2008]

Related Works (5)



□ [Varvello et al. 2007]

- Delaunay-based
 - **Cluster** creation when crowding
 - **Stretching** distances within cluster
 - ✗ **All** Delaunay flip operations are still performed
- } **High overlay maintenance cost**



Source : [Varvello et al. 2007]

The BIG Question...

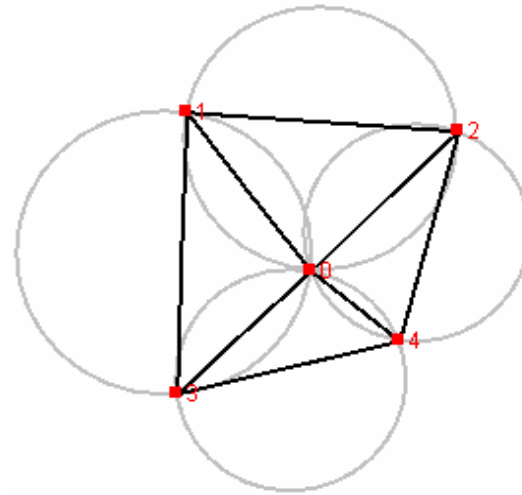


Voronoi/Delaunay : the right choice ?

Delaunay Triangulation for NVEs



A Delaunay triangulation for a set of vertices A in a 2-D plane is a triangulation $DT(A)$ such that no vertex of A is inside the circumcircle of any triangle in $DT(A)$



□ Features

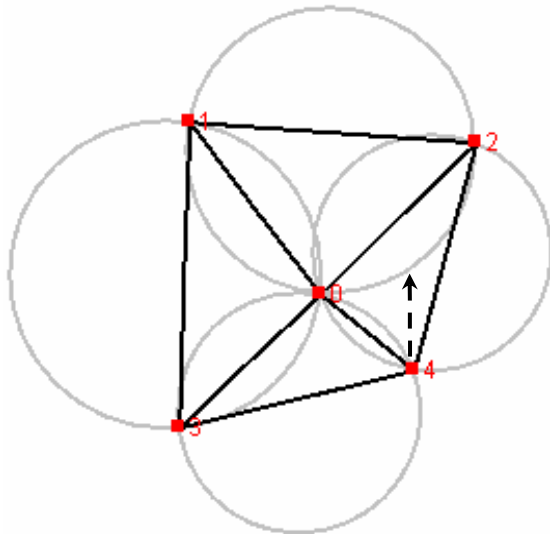
- Balanced triangulation
- Proximity-based => **Locality**
- Low number of neighbors => **scalability**
- Dual graph of **Voronoi** diagram => **state management**

Delaunay Triangulation for NVEs



□ Issue

- High connection change rate (*edge-flipping*)
- High maintenance cost in NVEs & MMOGs

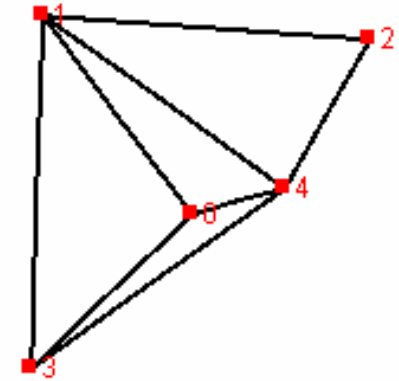


Before 4's movement



Edge-flipping

02 replaced by 14



After 4's movement

Perfect Delaunay Triangulation in NVEs

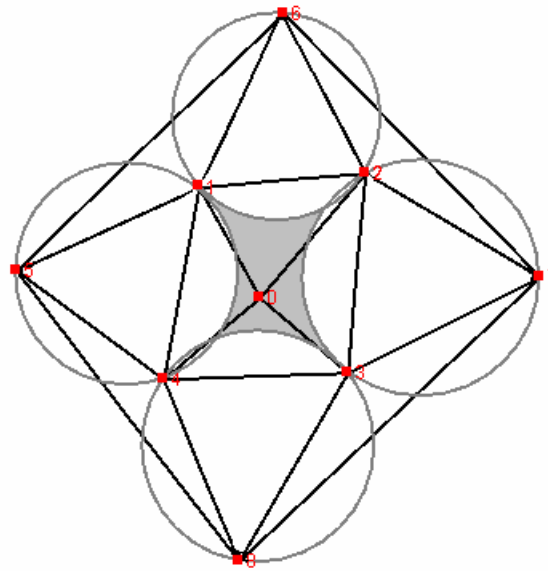
necessary or *sufficient* ?

Delaunay Revisited...



Flip-free area

Area where the node can move without triggering edge-flipping



Standard Delaunay

Basic Idea

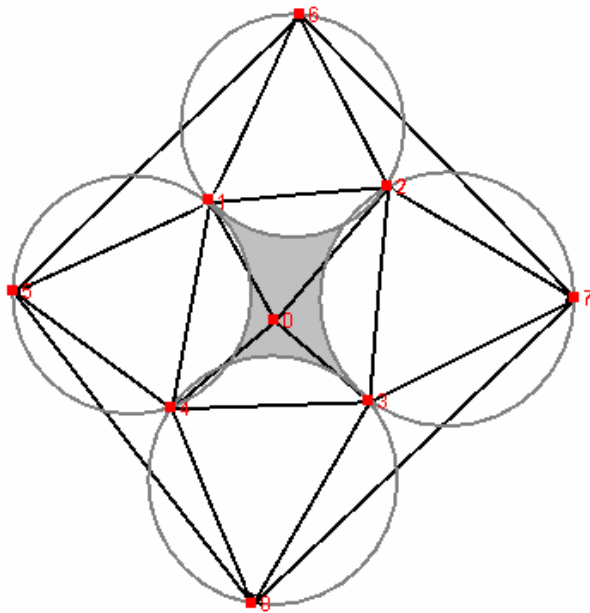
Reduce communication cost by **maximizing** a node's flip-free area while maintaining a **valid** triangulation

Delaunay Revisited...



Stretched flip-free area

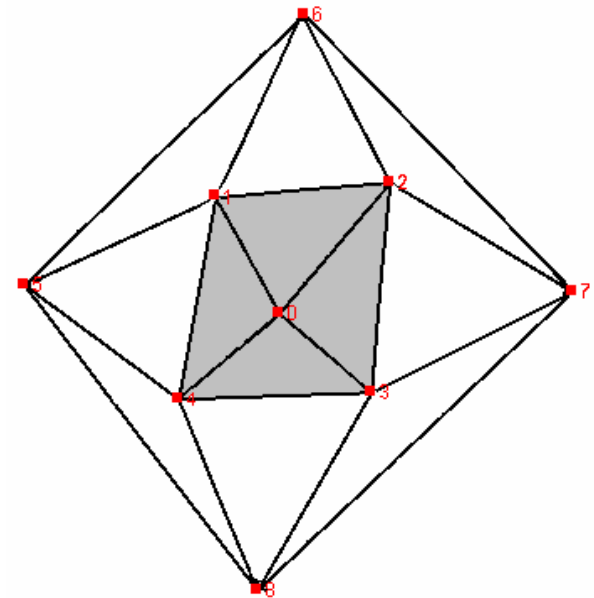
the region composed of all the triangles for which
a node is a vertex.



Standard Delaunay



Maximizing *flip-free*
region



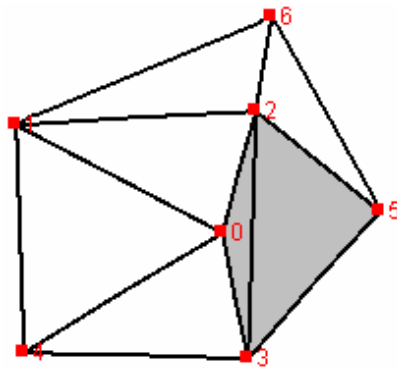
Our variation

Delaunay Revisited: node movement



Is flip-free area convex ? **YES**

Flip **only** when crossing the base of one of its triangles

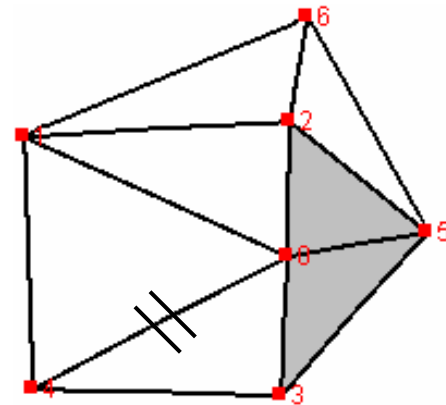


0 crosses base 23



Edge-flipping

23 replaced by 05



Increased degree ?

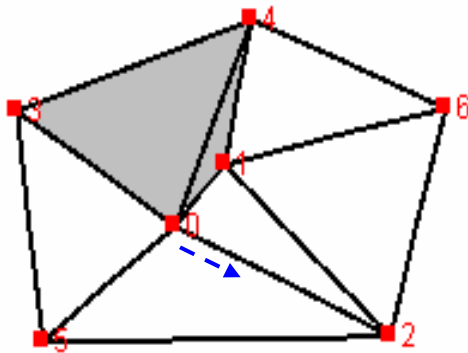
Flip w/ triangles having longest common edge

Delaunay Revisited: flip operations



Is flip-free area convex ? **NO**

Flip **only** when \Rightarrow crossing the base of a triangle
 \Rightarrow Triangle **anomalies** occur

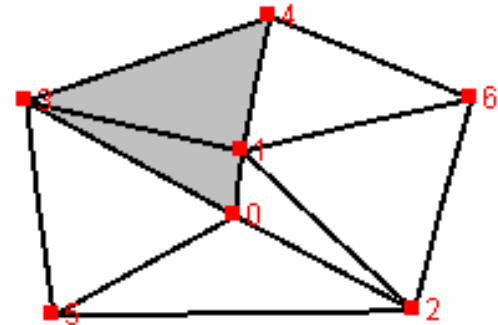


0 moves towards 2



Edge-flipping

04 replaced by 13

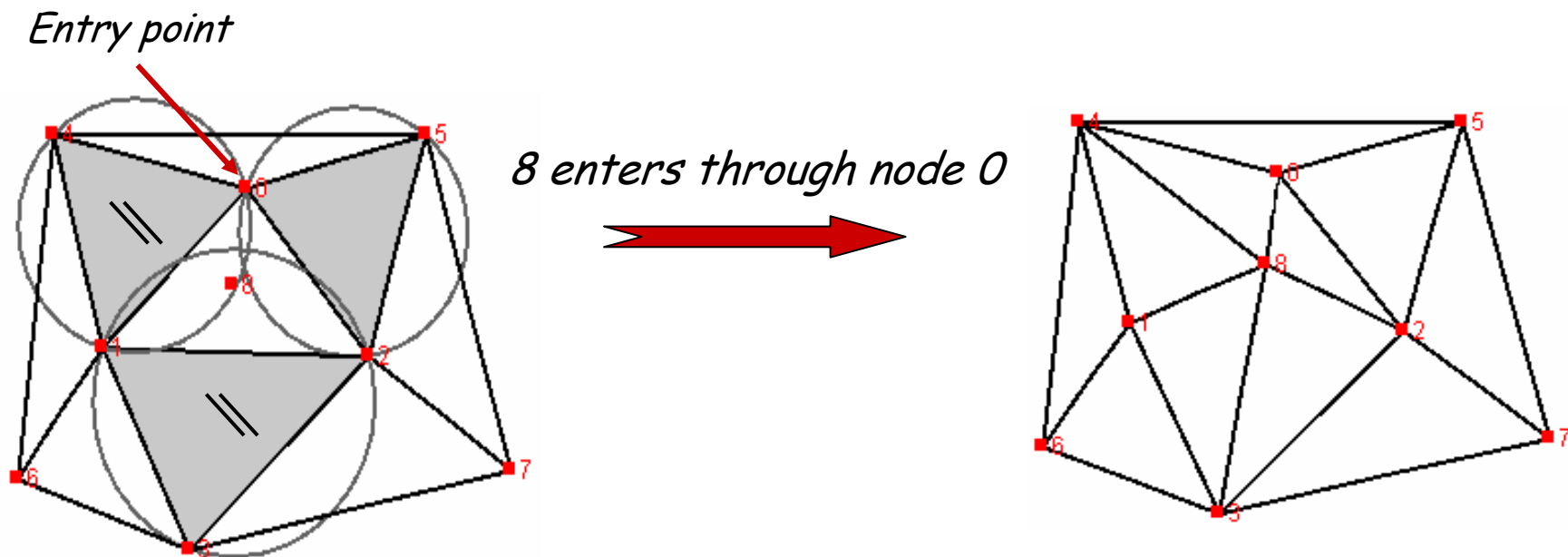


Delaunay Revisited: node insertion



□ n entering triangle T

1. check neighbor triangles w/ common edge with T
2. If n inside one of the circumcircles
 - Flip with the corresponding triangle(s)



- ❑ Is Delaunay/Voronoi the best choice for NVEs ?
- ❑ Consider weakening conditions/alternatives
 - Imperfect Delaunay is enough
 - What impact on corresponding Voronoi ?
 - **Region management, load balancing**, etc.
 - Voronoi dual graph not ideal for dynamic state management
- ❑ **Current work**
 - Formal analysis
 - Extensive evaluations w/ real traces (**MMOGs** and social **NVEs**)
 - **Latency vs message cost**
 - **Packets/sec**
 - Decorrelate state/object management from virtual position
 - **Dual overlay !**