STATE MANAGEMENT IN DISTRIBUTED VIRTUAL ENVIRONMENTS: A VORONOI BASED APPROACH

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PRESENTATION OUTLINE

• Voronoi Overlays: general features

• State Management in Voronoi-based Distributed Virtual Environments
  – Objects ownership
  – Persistency
  – Consistency
  – Optimizations: Forced Coordination Area

• Experimental Results
VORONOI BASED OVERLAYS

- Let $P = \{p_1, ..., p_n\}$ be a set of $n$ distinct peers (sites) in a 2(3)-dimensional space $S$.
- **Voronoi tessellation**: partitions $S$ into $n$ regions $V(p_j)$, $j \in 1..n$, paired with each $p_i \in P$, where $V(p_j)$ includes all the points $q$ such that:

$$\text{dist}(q, p_j) \leq \text{dist}(q, p_i) \text{ for } i \neq j$$

- **Delaunay Triangulation** connects two Voronoi regions sharing a border (Voronoi neighbours)
  - $O(1)$ neighbours in 2-dimensional spaces
- **Overlay Connections** = Delaunay links
- **Geometrical properties** of Delaunay Triangulation may be exploited to define efficient routing strategies
  - Compass Routing
  - AOI-cast
PASSIVE OBJECTS MANAGEMENT

- DVE Passive objects are characterized by a state
  - a door may be opened/closed
  - the level of a potion in a glass may change because an avatar drinks it
- In a pure P2P environment, peer should cooperatively manage the state of the objects
- **Main idea**: exploit the Voronoi tessellation to define a mapping of the passive objects to the peers
  - the coordinator, or owner of a passive object $O$, is the peer $P$ whose Voronoi region includes $O$
  - the ownership of an object changes during the DVE evolution, because of the movement of the peers
  - Ownership is always delegated
- Optimization: define a set of strategies to reduce the number of ownership changes in crowded regions
PASSIVE OBJECTS OWNERSHIP

- The owner of the object O1 is the peer P1 because it includes O1 in its Voronoi Area
  - P1 is the owner of O1 even if it cannot modify O1

Each object O is paired with

- Visibility Area of Interest ViAoI: (larger circle) portion of the DVE where O may be perceived

- Interaction Area of Interest IAoI (smaller circle) portion of the DVE where a peer must be located to interact with O
OBJECT PERSISTENCE

- The owner of an object may crash or voluntarily leave the overlay – churn problem

- The state of an object must be replicated onto a set of peers

- Replication is required by the game semantics
  - on object must be replicated onto any peer in its ViAoI, but....
  - the ViAoI of an object does not include any peer if the DVE is scarcely populated
  - further mechanisms are required to guarantee object persistence

- **OwnerShip forecast:** Voronoi Diagrams are exploited to detect the peers where the object should be replicated
A peer replicates an object $O$ onto its Voronoi neighbours, even if they are not in the ViAoI of $O$

Peer $b$ sends the state of $X$ to $a$, even if the ViAoI of $X$ does not include neither $b$ nor $a$

$a$ may recover the state of $X$ in case of a sudden crashes of $b$
The owner of an object $x$:
computes a Voronoi Diagram including all its neighbours, but not itself

detects which would be the owner of the object in the case of its crash

replicates the object on this peer

A sequence of Voronoi diagrams corresponding to different levels of replications may be computed
OBJECT CONSISTENCY

- the owner $P$ of an object $O$ acts as a temporary server for $O$

- the owner $P$ of an object $O$
  - receives the updates performed on $O$ by the peers in the $IAoI(O)$
  - modifies the state of $O$
  - broadcasts the updates to each peer belonging to $ViAoI(O)$

- updates are notified through static heartbeats
  - are generated when an object is modified/created
  - differ from dynamic heartbeats which are generated periodically to notify the movement of the peers
  - are propagated through the Delaunay overlay
  - $AOI$-cast defined by exploiting reverse compass routing
The owner of the object sends the state of the object $O$ to the other peers in the ViAoI of $O$ through a static heartbeat.
OBJECT CONSISTENCY

• Each peer in the IAoI of an object may modify it

• A set of strategies must be defined to resolve conflicts due to concurrent updates

• Strong consistency models vs. optimistic consistency models

• Different models may be exploited according to the object semantics

• Different types of objects
  – the big walls of a fortified city must be consistent to avoid that the player enter the city through a closed door
  – the state of the non player characters may be temporary inconsistent during the battle
An optimistic approach for the maintenance of the consistency:

- the state of an object $O$ is replicated at each peer in the ViAoI of $O$
- each peer $P$ modifies its local copy of the object
- the update must be committed by the owner of the object
- if the update is committed, a positive acknowledgment is sent to $P$ which renders the object on the user interface
- otherwise a negative update is sent to the owner of the object and the update is retried
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FORCED OWNERSHIP

• ownership is always delegated

• a ping pong effect may occur, especially in crowded areas

• a pair of Voronoi neighbours may continuously exchange an object $O$, due to their movement, because their common Voronoi edge steps over the object

• introduction of the Forced Coordination Area of Interest (FCAoI)
  – an area centered at the object
  – the owner does not delegate the ownership of an object if it belongs to the FCAoI, even if the object is not located in its Voronoi Area
EXPERIMENTAL RESULTS

- a set of simulation developed through Peersim, a scalable simulator for testing P2P overlays
- 1000 peers, 3000 objects
- random movement of the peer within the Dve
- our goal: evaluate ownership changes as a function of
  - Peer speed
  - Radius of the Forced Coordination Area
EXPERIMENTAL RESULTS

Ownership Changes for each Cycle

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EXPERIMENTAL RESULTS

Average Max number of Ownership Changes for each Cycle

Radius (x5 -5)

Average Max Num Changes

Vel 1
Vel 2
Vel 3
Vel 4
Vel 5
EXPERIMENTAL RESULTS

Average Max number of Objects Owned

Objects Owned

Radius (x5 -5)

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CONCLUSIONS

- A Voronoi based approach for the management of passive objects
- Voronoi diagrams are exploited for defining
  - objects ownership
  - object persistence
- Optimizations for reducing ownership changes
- Optimistic consistency strategies
- Future work
  - investigate further optimistic consistency models
  - implementation on a real platform