1500 Archers on a 28.8: Network Programming in Age of Empires and Beyond

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Introduction

• This page explains Age of Empires (AoE) 1 and 2 multiplayer implementation.

• Explains:
  - Design Architecture
  - Implementation
  - Lessons learned

• Also for the "future" RTS by Ensemble
  - (Age of Mythology, AoM)

Outline

• Introduction (done)
• Implementation (next)
• Lessons Learned
• Improvements for AoE 2
• RTS3
• Summary

AoE: Multiplayer Design Goals

• Support for 8 players
• Smooth simulation over modem, Internet, LAN

• Target platform: 16 MB P-90, 28.8 modem
  - (AoM is PX-450, 56.6 modem)
  - At 15 frames per second (one frame every 67 ms)

• Use (existing) Genie engine
  - next
AoE in Early Stages (1 of 2)

- Game engine was running
  - 2d, single-threaded game loop
  - Sprites in 256 colors
  - Reasonably stable
- Large map, thousands of objects, trees could be chopped, animals ran around ...
- Breakdown:
  - 30% graphic rendering
  - 30% AI
  - 30% simulation
- "Compelling" single-player game already
  - (ie: "Don't ruin it!")

AoE in Early Stages (2 of 2)

- Wanted: army on army, large supporting structure, ...
  - (1500 archers on a ...)
- Time to complete each simulation step varied:
  - Render time changes with number of units
  - When scrolling
  - AI computation time varied with units or time
  - As much as 200 ms (larger than a frame time!)
- Bandwidth a critical resource:
  - Passing x,y coordinates, status, action, facing damage ...
  - Limit of 250 moving units at most
  - (MLC: 1 bytes each \( \times 6 \) actions \( x \) 250 units \( x \) 15 updates per second \( \approx \) 160 Kbps)

Simultaneous Simulations

- Each PC ran exact same simulation
  - Synchronized game time
  - Synchronized random number generators
- Still
  - Internet latency from 20 to 1000 milliseconds
  - Variable time to process each step
- Needed a more responsive approach

Communication Turns

- Separate communications turns from frame rendering
- Schedule commands for later time
  - Allows for some variance in network and turn processing
- Turns typically 200 ms in length
  - Send all commands entered that turn, but schedule them for 2 turns later
  - Process any scheduled turns

The Need for Speed Control

- Since all machines in "lock step", can only run as fast as slowest machine
  - Process communications, render turn, send out new commands
- "Lag" if
  - One machine slows down and others wait
  - Delayed or lost Internet data

Speed Control

- Each client calculates frame rate
  - Since varies with game state, use moving average
  - Send with "Turn Done" message
  - Use to achieve "minimum" frame rate
- Each client measures round-trip "ping" time
  - Since varies with Internet traffic, use largest for all players (MLC: assume moving average)
  - fps + rtt \( \rightarrow \) 2-bytes total overhead
- After getting "Turn Done" messages
  - Adjust target frame rate (based on local PC render rate)
  - Adjust communication turn (based on ping-times + remote PC render rates)
  - Weighted, so only "laggy" during worst spikes
- (Examples next)
**Speed Control**

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<th>Method of Messages</th>
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1) Typical communication turn

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2) High latency, normal machine

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3) High latency, slow machine

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**Transport Protocol - UDP**

- Unreliable, so each client handles command ordering, drop detection and re-sending
  - When in doubt, assume it dropped
- Messages arriving from past turns are discarded
- If out of order message received, request a resend of supposedly "missing" messages
  - Note, if really out of order, will get duplicate so must account for
- If ack is "late", then assume lost so resend

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**Side Benefit - Cheat Prevention**

- Simultaneous simulations means games are identical
- If there is a discrepancy, game stopped
- Prevents cheaters from using hacked client
- But there still could be cheating via information exposure

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**Side Problems - Out of Synch**

“In every project, there is one stubborn bug that goes all the way to the wire…”

- Microsoft product manager

- Subtle, since small errors multiply
  - Example – a deer slightly out of alignment, causes villager to "miss" so no meat, causing different food amounts
- Checksums (objects, pathing, targeting …), but always something
  - Wade through 50 MB of message traces
  - (MLC: different game states when commands are lost or are too late?)

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**Lesson: Know Your User**

- Each genre is different
  - RTS
  - FPS
  - Sports
  - MMORPG
  - …
- 1) Know latency expectations
- 2) Prototype multiplayer aspects early
- 3) Watch for behavior that hurts multiplayer performance
Know Your User - Expectations

- Simulated latency with single-player engine
  - Look for: good, sluggish, jerky, horrible
- For AoE
  - 250 milliseconds (ms) not noticed
  - 250-500 ms playable
  - 500+ ms noticeable
- Consistent slow (500 ms) better than “jerky” (80 ms - 500 ms)
  - Suggested picking conservative turn length
  - Make change to new turn length gradually

Know Your User - Actions

- Users clicked once per 1.5 – 2 seconds
- During battle, spikes of 3-4 clicks per second
- Many of the commands are repeats
  - Turn is longer than command
  - Unit takes several turns to process
- Add “filter” to remove repeat commands

Lesson: Metering is King

- Make performance meters human readable and understood by testers
  - Need to educate testers
  - Testers can notice differences, help determine where problems are
- Keep running all the time
  - Low impact
  - Early development measurements may change in later game

Lesson: Educating the Developers

- Get programmers to think about multiplayer (distributed systems!)
- Multiple, independent processing
  - Command request might happen later (or not at all)
- Additional calls to random numbers can throw off synchronization
  - Random sounds or animations on high-perf computers need to save and re-seed to keep random in-synch

Misc Lessons

- Verify 3rd party code (AoE used Microsoft’s DirectPlay)
  - Is “guaranteed delivery” guaranteed?
  - Does product have hidden bottlenecks?
- Create simulations and stress tests
  - Isolated connection flooding, simultaneous connections, dropping of guaranteed packets...
- Test with modems as early as possible
  - Hard to isolate network problems (ex: could be ISP)
  - Helps make sure not the networking part
  - Although tests harder (and not as fun), do as many modem tests as LAN tests

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- Implementation (done)
- Lessons Learned (done)
- Improvements for AoE 2 (next)
- RTS3
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Improvements for Age of Empires 2 - the Age of Kings

• New multiplayer features
  - Recorded games
  - File transfer (custom maps)
  - Statistics tracking (on "The Zone")
• Recorded games helps in debugging
  - Can replay exactly to spot problems

Outline

• Introduction (done)
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• Lessons Learned (done)
• Improvements for AoE 2 (done)
• RTS3 (next)
  - Overview
  - New features and tools
• Summary

RTS3 - Beyond AoE

• RTS3 is "codename" for next generation
  Ensemble RTS (probably Age of Mythology)
• Add 3-d capability (used BANG!)
• Multiplayer requirements
  - Again, complex maps, thousands of units,
    Internet play
  - More than 8 players (AoM allows 12)
  - Still modem, but 56.6k
  - May be firewalls and NAT boxes so peer-to-peer harder

RTS3

• Forget DirectPlay → created own library
  - Use in subsequent games
  - Integrated with BANG!
• Fully 3-d world meant frame rate maybe an issue
  - Overall smoothness from frame rate impacted
  - Also more variation
• Realized play-testing was iterative, so
  wanted multiplayer running earlier

An OO Approach

Peer-to-Peer Topology

• Strengths
  - Reduces latency
  - No central point of failure (can continue game if one client leaves)
• Weaknesses
  - More active connections (n)
  - Impossible to support some NATs

(Make protocol specific parts as small as possible)
**Net.lib (1 of 2)**

* Level 1: Socks
  - Fundamental C API, Berkeley sockets
* Level 2: Link
  - Transport layer services
  - Packet, Link, Listener, Data stream, Network Address, Ping

**Net.lib (2 of 2)**

* Level 3: Multiplayer
  - Client, Session, Channel (ordered or unordered), Time Sync
* Level 4: Game Communications
  - RTS functionality (could define others for different genres)

**New Tools and Features**

* Improved synch
  - Geared towards rapid turn around time from out-of-synch bugs
  - Compile-out extra synch debugging code upon release
* Console commands and config
  - Simple text "hooks" to game engine
  - In multiplayer, passed to other clients and executed there
  - Testing without writing additional code

**Summary**

* Peer-to-Peer for responsiveness
* Synchronous simulation for scalability
* Compensation for heterogeneity in clients and variability in networking
* Overall
  - Multiplayer "feels" like single player
  - Success!