

11 Networking in Games

Tvorba a dizajn počítačových hier

Návrh a vývoj počítačových hier

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5. 12. 2024

Motivation

- Online statistics & analytics
- Online storage of user state
- Online software and content updates
- Communication with 3rd parties
- Multiplayer
- We will focus on the hardest of these, multiplayer

Types of Multiplayer

- Asynchronous (Clash of Clans)
- Turn-based games (Chess, Hearthstone)
- Simple real-time games (Clash Royale)
- Fast action games (Counter-Strike, Fortnite, Overwatch...)
- MMO games (World of Warcraft...)

Multiplayer – Basic idea

- Player input modifies game state
- Game state is synchronized across the network
- Each player modifies only a subset of the game state
 - What would happen if multiple players controlled the same objects?
- The usual approach uses client-server communication
 - The whole level has one server – could be one of the players or a **dedicated server**
 - Other players are connected to the server

Client-Server model

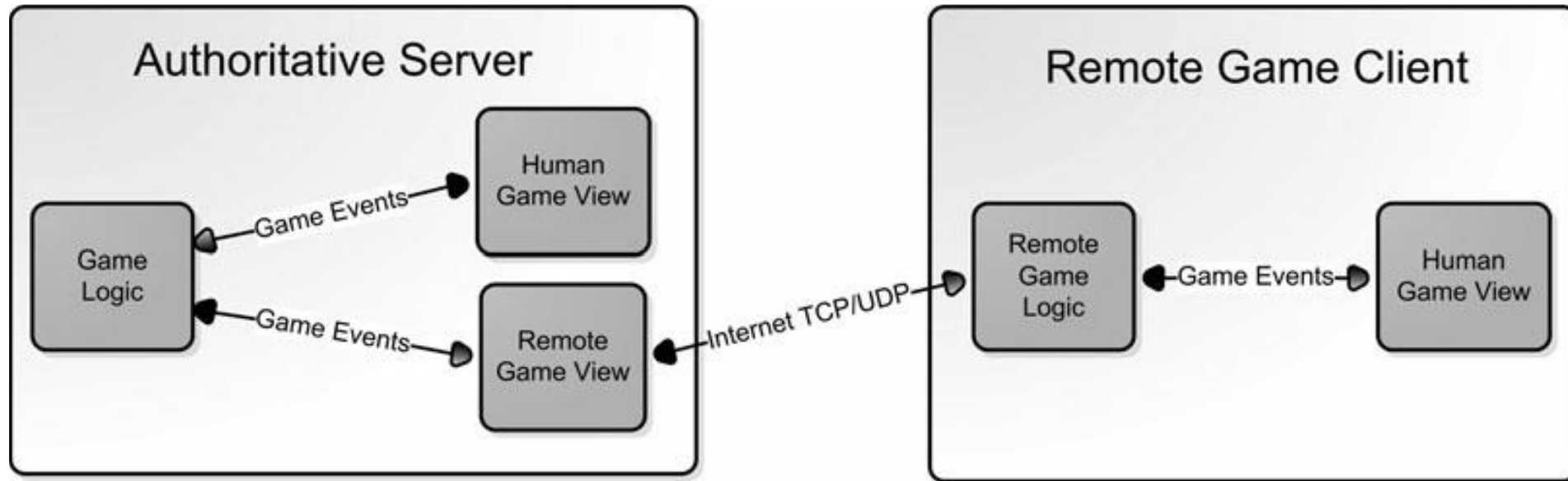
- Connection-based approach
- **Server** – provides a service (game state)
- **Client** – requests the service from a server (access/modify game state)
- Multiple clients communicate with one server, never between each other
- Centralized system, high demands on server resources
 - Especially for MMO games such as World of Warcraft
- Low player numbers can be handled by a normal PC and internet connection
 - Counter-strike, Starcraft, ...

Relation to the Observer pattern

- Game state on the server (subject) is being observed by clients (observers)
- Clients get notified on state changes
- Clients send their data to modify the state
 - But the server decides what to modify (to avoid cheating)
- **Both parties receive data with a delay**

Networked Game through Views

- We implement two additional classes to enable networking
 - Remote game view
 - Remote game logic
 - Proxy design pattern



Remote Game View

- On the server, a remote player is just like an AI agent
- What happens inside the game view is totally different
- Game events are packed up and sent via TCP or UDP to a client
 - Need to compress data, select only important game events
 - No need to send “object moved” if several such events occurred since the last packet was sent, we send only the most recent
- Receives game commands from the client
 - Should not trust these entirely
 - Need sanity checks to prevent hacking
 - After filtering impossible commands, they are passed on to the game logic

Remote Game Logic

- The game logic is an authoritative server, it represents the real game state
 - Clients need a copy of the game state to be able to present the player the game correctly
 - They also need to account for network delays and network errors
 - This is the job of Remote Game Logic
- It is similar to server game logic
 - There is a need to simulate without receiving events from the server
 - Saves bandwidth
 - Increases responsiveness
- Allow for “against the rules” corrections when the server sends the correct data

Typical Client-Server interaction

- Client sends a request to create a new connection for it on the server
- Server receives the request and prepares a connection, then notifies the client
- The client sends data through the connection (over and over)
- When the server receives data from a client, it is notified and responds based on the data
- The client is finished (player turned off the game) and notifies the server to abort the connection
- If any of the sides does not respond within a reasonable time frame
 - Time-out occurs, connection is lost
 - Handle the disconnect automatically

Peer-to-peer networking

- Alternative to client-server
- Decentralized system
- All nodes are equal, there is no server
- Distributed resources, part of resources available on each node
- Very rarely used in games
 - Not reliable communication between multiple players
 - More vulnerable to cheating attempts
 - Depends on players' connection quality

Multi-server network architectures

- Used for MMOs
- Multiple distributed servers that communicate between each other and each has several clients connected
- The servers connect nearby clients, clients that are in the same location...
- Complicated load balancing
- Can sustain millions of players (World of Warcraft)
 - But not all interacting at the same time
 - In-game locations have their limits on the number of players

Low-level protocol

- UDP – User Datagram Protocol
 - Connection-less communication
 - Packets are always sent to a specific IP address and port
 - Unreliable protocol
 - Order of packets is not guaranteed, need to split your data into packets
 - Delivery of packets is not guaranteed (1-5% loss)
 - Duplicated packets can occur
- TCP/IP – Transmission Control Protocol
 - Connection-based communication
 - Guaranteed order and reliability
 - Splits your data into packets automatically – just write/read data to/from a stream
 - Flow control
 - Easy-to-use, just like writing/reading data to files

**Which one is used in
real-time multiplayer games?
UDP or TCP?**

Problems with TCP/IP

- Input and output streams (“files”) are buffering data on both sides and decide when to send the data
 - Lots of small-sized data (such as player commands) might be buffered for seconds before sending
- Possible fix: set `TCP_NODELAY` to send data immediately
- If packets are lost or come out of order, they are sent again or re-ordered
 - If it happens again, it tries again
- This may cause huge latency problems (seconds)
- TCP is basically UDP with added overhead, that splits your data into packets, numbers them, and then checks them on the other side

High latency in TCP

- If we have problems reconstructing the packets, stalls occur
- Depends on the ping between both sides
- On packet loss, stalls might reach duration of $3 \times$ latency
- If new data was sent during that time, TCP **forces** it to wait for the old data
- Therefore, most real-time games use UDP
 - But with added features
 - Some games mix TCP and UDP – different for fast and for reliable data
- TCP can be used for games that do not need fast real-time communication
 - Turn-based games
 - Online statistics, analytics
 - Saving user data
 - Important communication – players buying something, ...

Problems with network games

- High latency
- “Lag” – Round trip time (RTT)
 - How long it takes to send a packet to the other network node and receive an answer
 - Latency = $0.5 * RTT$
- “Jitter” – Fluctuation of latency between packets
- Packet loss – as mentioned before

Avoiding problems

- Reducing the distance between end nodes
 - 12.000km distance, light travels at 300.000km/s => 40ms latency
 - This is the lowest bound, since we are limited by the speed of light
- Getting a better internet connection 😊
 - Not really an option, since players want to play in their current setup
- Not much we can do to reduce these
- We can improve by:
 - Sending consistently large packets to avoid jitter
 - Reducing packet size – sending only essential data
 - Not requiring packet ordering (UDP in favor of TCP)
 - Split data based on importance and required latency (combining UDP & TCP)

Latency compensation techniques

- There is nothing we can do about latency (physics...), so let's try to compensate
- Prediction techniques
- Manipulation of game time to equalize gameplay
- Data compression
- We need to be careful, since we might be opening doors for cheating
 - Cheat detection

Prediction

- The client predicts the server response and presents the game state as it is
- The game responds immediately to user input
- The game state might diverge from the actual (server) game state
- Higher latency \Rightarrow bigger differences in states
- Repairing of game state when the server message is received
- Player “prediction”
 - Let the user interact, expect what will be received concerning only this player
- Opponent prediction
 - Predict positions (and lots more...) of entities not controlled by the player

Player “prediction”

- We need to keep the game state *reasonable* while we wait for the server to respond
- The player is allowed input, however some of their actions might be undone later, when the client “repairs” the game state according to the server
- Introducing tears and “teleports” is a negative side-effect, however not so bad as stalling until new information is received from the server
- Can be in the form of calculating correct physics, allowing player movement and actions

More responsive \Rightarrow Less consistent

More consistent \Rightarrow Less responsive

Opponent prediction

- We take the opponents' entities, their last known position and where they are heading
- Predict position based on direction and speed
- Take it as the truth if we do not receive an update
 - which will be retrospective!
- We might need synchronized Random Number Generators (RNGs)
 - An opponent fires a gun, it does between 15 and 30 damage
 - RNG can make the difference between a unit dying or surviving
 - Pseudo-RNG are initialized with the same seed value on all clients and the server
 - Usually used in RTS games (Warcraft 3 does this)
 - Avoiding RNG in game design is also valid

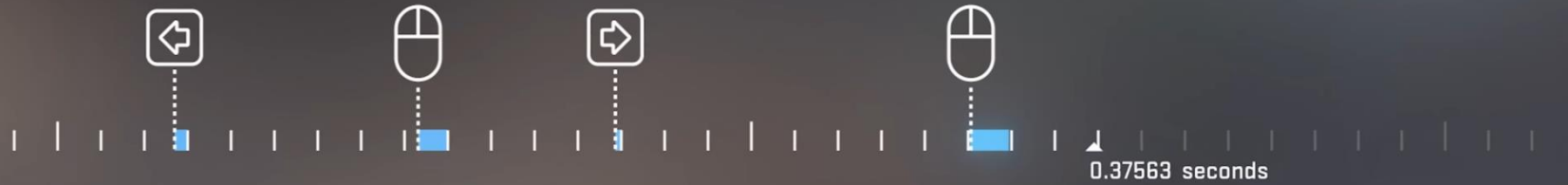
Opponent prediction in FPS games

- Position P , Velocity v , last received packet at time t_0 , current time is t
- Very simple linear prediction: $P(t) = P + v \cdot (t - t_0)$
 - We additionally use the physics engine to avoid displaying the enemies running through walls
- Causes an unsolvable problem
 - Firing at the opponent at a predicted position
 - The server receives only your position and direction when you shoot
 - You clearly see that you are firing directly at them
 - The server knows better, and the opponent does not die

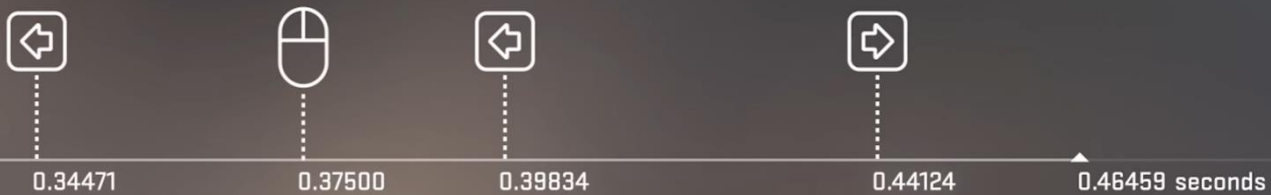
Adjust send rate

- Send some data only X times per second = **send rate**
- If the game is running at 200 FPS, update just a small amount of necessary data every frame
- Example: CS:GO – 64 updates per second (*tick rate*), 128 in tournaments
 - CS2 “sub-tick rate” still does 64 updates per second
 - But evaluates actions with precise timestamps
- Different data in-game can have different send rate
- Should not depend on framerate
 - All network communication usually runs on a separate thread

SOURCE 1
TICKS



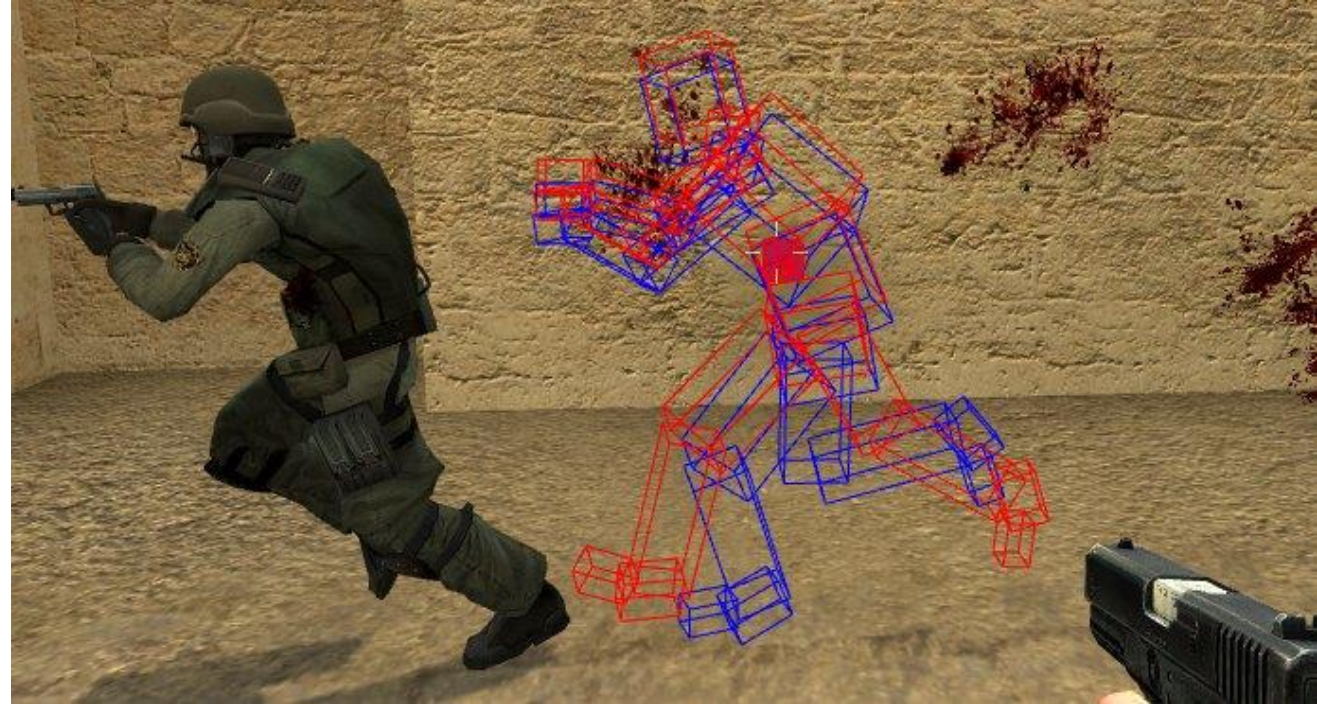
SOURCE 2
SUB-TICK UPDATES



Images from
<https://www.youtube.com/watch?v=GqhhFI5zgA0>

Time warping

- The client has fired a shot
 - At $t_0 = 0$
- The server received the message
 - At $t_1 = 100\text{ms}$
 - The enemy moved left in the 100ms
- Red boxes – Show the position of the enemy where it was on the client in time $t_0 = 0$
- Blue boxes – Position estimated by the server after a time warp
 - The server rolls time back
 - Using the game time from the client



Opponent prediction in RTS games

- Each unit has received a command
- Clients receive only a list of commands for a list of units
- Units can keep executing their commands
 - Must be **deterministic**
- More consistent than FPS games
 - Commands for one unit do not change as often as the position or rotation of the player
- Example:
 - Max actions per minute (APM) for pro RTS players is around 600
 - 10 actions per second \Rightarrow 1 action/packet every \sim 100ms
 - Compared to 128 tick servers in CS:GO \Rightarrow 1 packet every \sim 8ms

Data compression

- Lossless compression
- Opponent prediction
- **Delta compression** – Send only state changes, not the whole state
- **Interest management** – Send only info that the player can see
- (Peer-to-peer)
- Update aggregation
 - Group multiple messages (can be from different moments in time) into one
 - Problematic with real-time games

Cheating

- We cannot trust packets we receive from the clients
 - Someone might be altering them
 - Or it might not be a game client at all, but a custom-made program trying to mess up our server
 - We need some “correctness” detection on the server
 - Ignore packets that update position of players too rapidly
 - Ignore unnatural Interest management packets
- Most typical cheats
 - Wall-hack, map-hack, speed-hack, aim-bot

Wall-hacking/map-hacking

- Wall-hacking: seeing through walls in FPS games
- Map-hacking: ignoring fog of war in RTS games
 - Showing enemy units in fog of war
- The hack alters the game window and renders additional objects on top of the game's output image
- Monitors memory/packets to identify position of units
 - All unit info is received over the network – man-in-the-middle attacks
 - Special algorithms to find the data in memory
 - Or a directly altered executable

Speed-hack

- Alters memory of the process
- Send “impossible” movement data to the server
- If the server is not validating it, it just accepts incorrect data

Aim-Bot

- Read positions of enemies from process memory or network
- Directly alter rotation of player in memory
 - Or generate fake mouse movement

Anti-cheating

- Network encryption
 - SSL or other encryption methods
- Monitor memory reading/writing attempts
 - Usually by a different anti-cheat process
- Encrypt data in memory
- Protect executable from cracking attempts – e.g. Denuvo
- CheatEngine is a simple tool for accessing memory of other processes
 - **Use at your own risk, never cheat online**
 - *Removing challenges makes the game less fun*

Networking in Unity

- Simple communication over HTTP/HTTPS
 - UnityWebRequest, C# HttpClient/HttpRequest
- UDP/TCP communication
 - C# TcpClient, TcpListener, UdpClient, Socket
- Unity UNet – old, deprecated
- [Unity NetCode](#) – part of DOTS
- [NetCode for GameObjects](#)
 - Evolution of Unity UNet + NetCode

Non-Unity Network Solutions


- [Mirror](#) – based on UNet (old Unity networking)
 - open source
 - Offers different low level transports
- [Hazel](#) – fork of an old library, currently in use by Among Us
 - Open source
- [Photon](#) – several different solutions

Photon

- Has several solutions for networking, each with specific use-cases
- **Quantum** – deterministic engine, high cost
- **Realtime** – cross-platform, for various engines, lower-level
- **PUN (Photon Unity Networking)** – easy to use, built on top of Realtime
- **Bolt** – for Unity, relatively easy to use, built on top of Realtime
- **Fusion** – new, Unity-only, has various improvements over PUN and Bolt
 - allows different network architectures

Photon – Pricing

Development Only		
20 CCU	DEVELOPMENT ONLY	FREE ▾
For Launch		
FREE 100 CCU	ONE APP ONLY	FREE ▾
100 CCU	ONE-TIME FOR 12 MONTHS	\$95 ▾
500 CCU	PER MONTH	\$125 ▾
1000 CCU	PER MONTH	\$250 ▾
2000 CCU	PER MONTH	\$500 ▾

	PUN	Bolt	Fusion 
	2011	2014	2021
Target Player Count	32	32-50	200
Core-Features			
Tick based simulation	✗	✓	✓
Client Side Prediction	✗	✓	✓
Lag Compensation	✗	✓	✓
Snapshot Interpolation	✗	✓	✓
Replication System			
Delta Snapshots	✗	✗	✓
Eventual Consistency	✗	✓	✓
Performance			
Allocations (Runtime)	/	/	zero
Performance (Benchmarks)	+	+	+++
Bandwidth	/	+	+++
Bespoke Prebuilt Functionality			
Area of Interest (AOI)	✗	✗	✓
Network Animator	✗	✗	✓
Network Character Controller (KCC)	✗	✗	✓
Auth. Rigidbodies w/ CSP	✗	✗	✓

Fusion

High-End State Synchronization Networking

- Snapshot Interpolation
- Full Prediction Systems
- Lag Compensation
- High Player Count

Photon Fusion is an evolutionary leap in high performance multiplayer on multiple topologies.

[EXPLORE >](#)

Quantum

Blazing Fast Deterministic for Unity

- No Netcode
- Zero Lag & E-Sport Grade
- Cheat Protection
- Bot SDK

Photon Quantum is a full deterministic multiplayer engine which can predict & rollback on physics, inputs, and more.

[EXPLORE >](#)

Games built with Photon

- Stumble Guys
 - 32 players per race
 - 25M Daily Active Users (DAU)
- Humankind, Robocraft, Phasmophobia, VRChat, Golf Clash, Ylands, Outward, Prison Architect, Descenders, Among Us VR

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