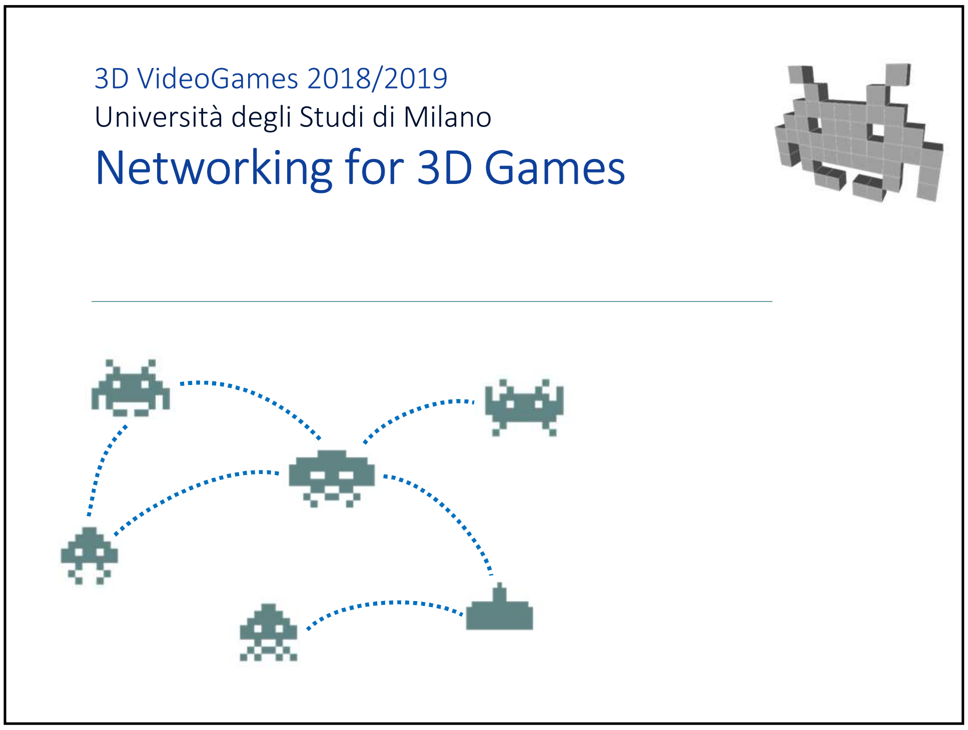

3D VideoGames 2018/2019
Università degli Studi di Milano

Networking for 3D Games

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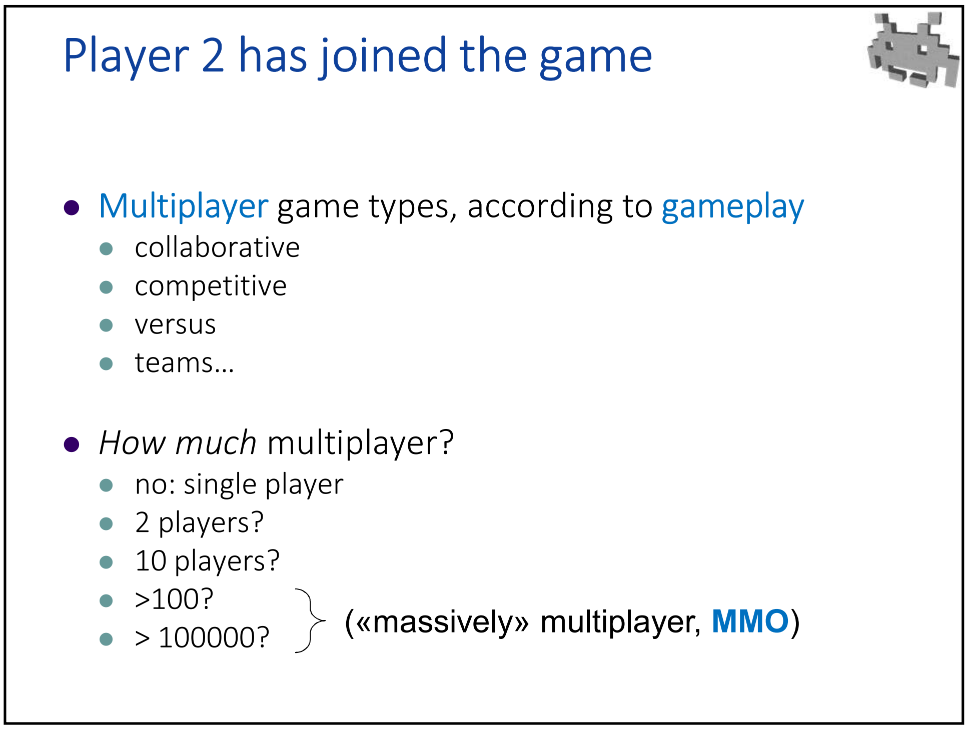

Player 2 has joined the game

- Multiplayer game types, according to gameplay
  - collaborative
  - competitive
  - versus
  - teams…
- *How much* multiplayer?
  - no: single player
  - 2 players?
  - 10 players?
  - >100?
  - > 100000?

  («massively» multiplayer, **MMO**)

2

Player 2 has joined the game

- Multiplayer game types
  - Hot seat
    - players time-share
  - Local multiplayer (Side to side)
    e.g. Split screen
    - players share a terminal
  - Networked
    - each player on a terminal
    - terminals connected
      - over a LAN
      - over the internet
      - …

Needs networking

3

Networking in 3D Games

Objective: all players *see* and *interact with* a common 3D virtual world

how can this illusion be achieved?

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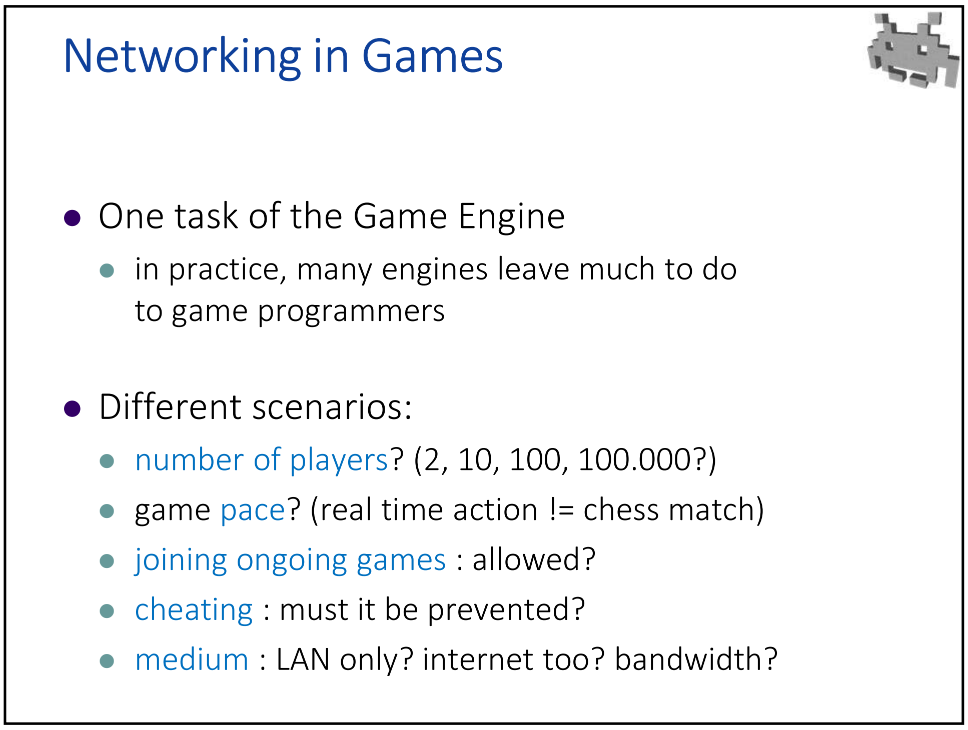
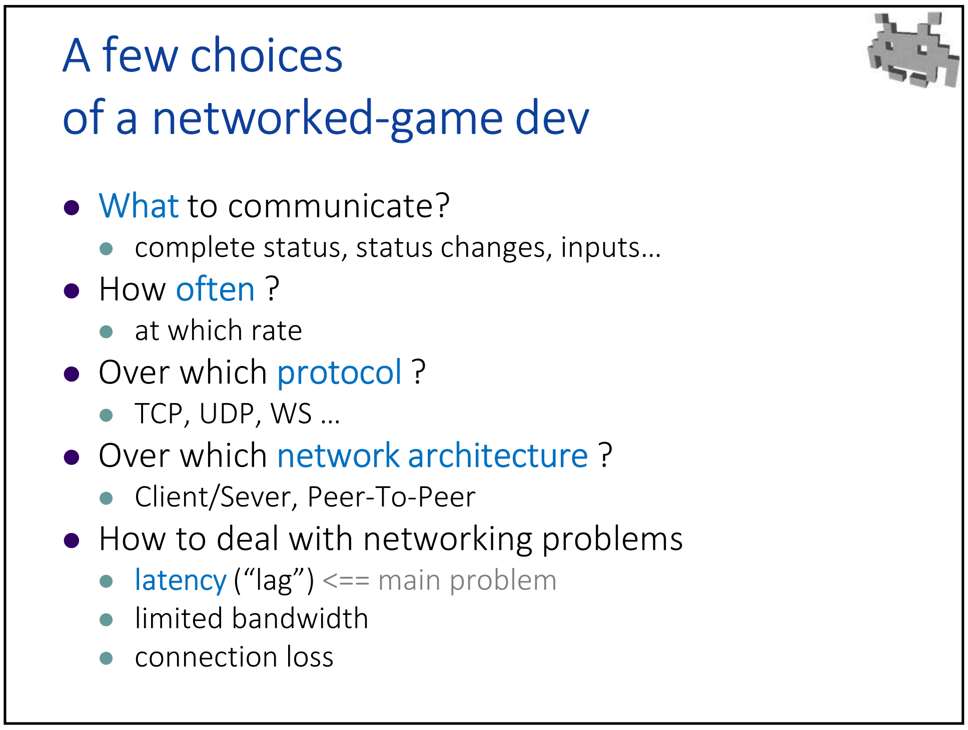


Networking in Games

- One task of the Game Engine
  - in practice, many engines leave much to do to game programmers
- Different scenarios:
  - number of players? (2, 10, 100, 100.000?)
  - game pace? (real time action != chess match)
  - joining ongoing games : allowed?
  - cheating : must it be prevented?
  - medium : LAN only? internet too? bandwidth?

5



A few choices of a networked-game dev

- What to communicate?
  - complete status, status changes, inputs…
- How often ?
  - at which rate
- Over which protocol ?
  - TCP, UDP, WS …
- Over which network architecture ?
  - Client/Sever, Peer-To-Peer
- How to deal with networking problems
  - latency ("lag") <== main problem
  - limited bandwidth
  - connection loss

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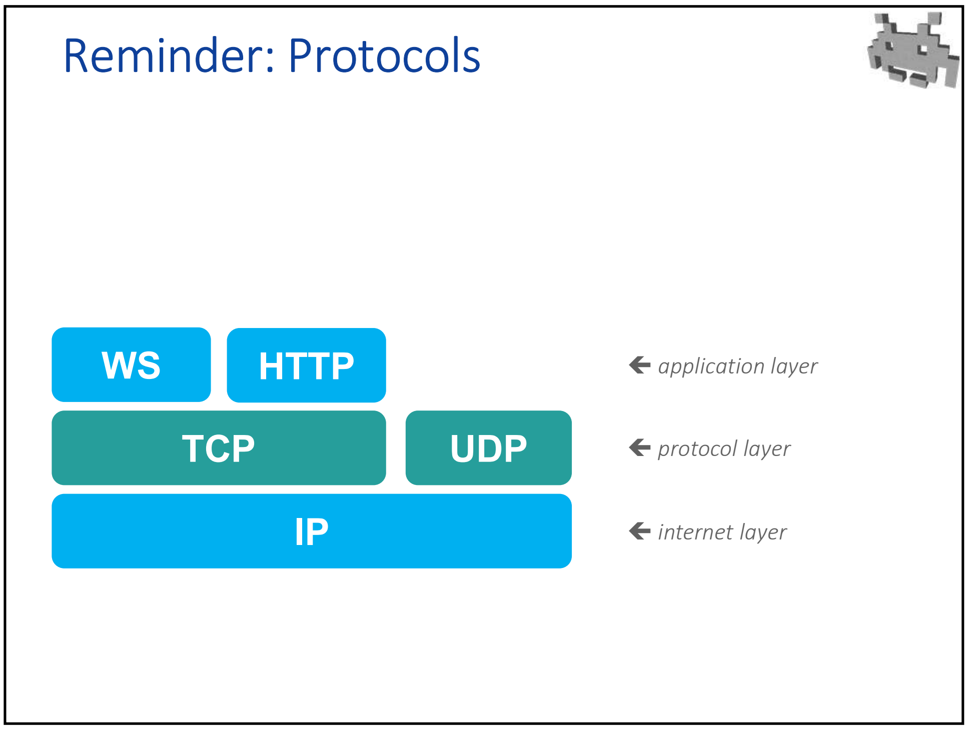

Reminder: Protocols

WS	HTTP	← *application layer*
TCP	UDP	← *protocol layer*
IP		← *internet layer*

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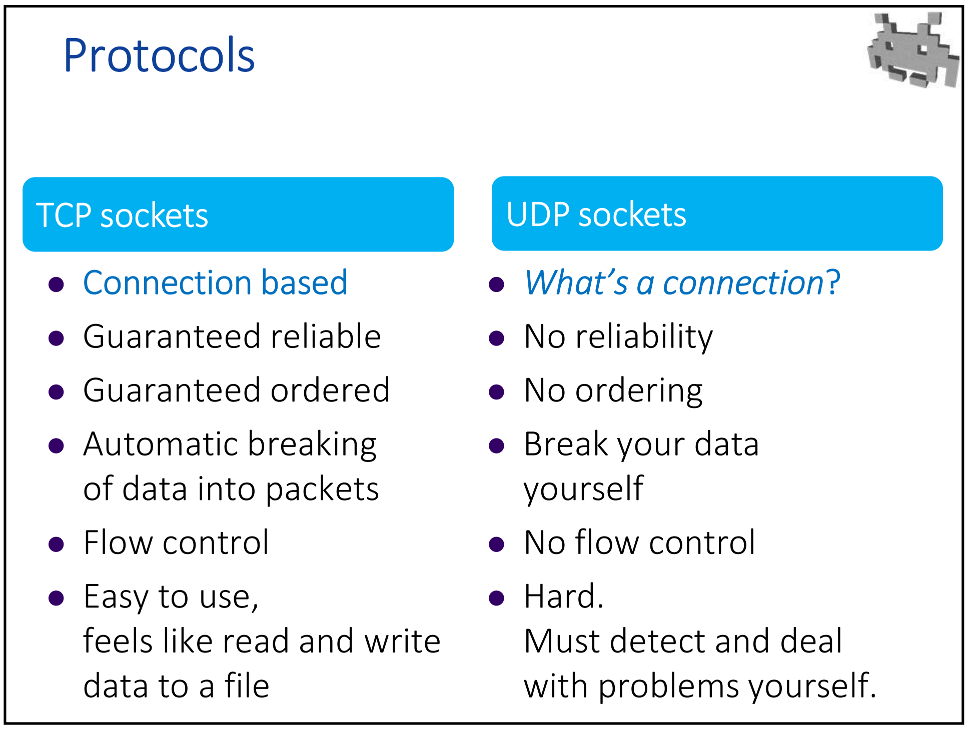

Protocols

TCP sockets	UDP sockets
Connection based	*What's a connection?*
Guaranteed reliable	No reliability
Guaranteed ordered	No ordering
Automatic breaking of data into packets	Break your data yourself
Flow control	No flow control
Easy to use, feels like read and write data to a file	Hard. Must detect and deal with problems yourself.

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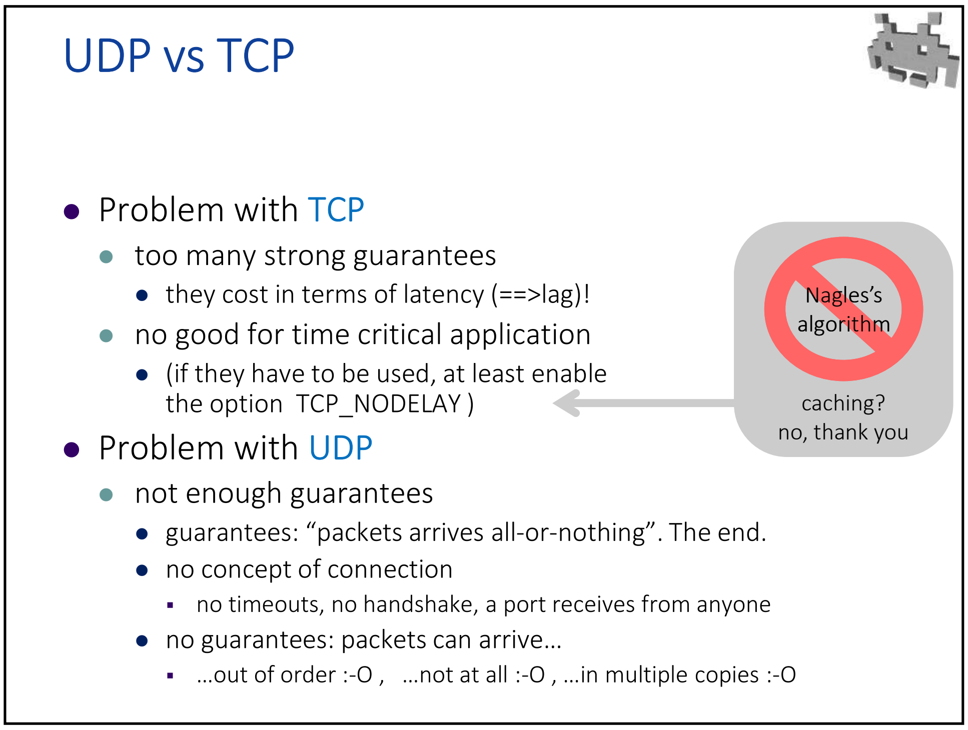

UDP vs TCP

- Problem with TCP
  - too many strong guarantees
    - they cost in terms of latency (==>lag)!
  - no good for time critical application
    - (if they have to be used, at least enable the option TCP_NODELAY)
- Problem with UDP
  - not enough guarantees
    - guarantees: “packets arrives all-or-nothing”. The end.
    - no concept of connection
      - no timeouts, no handshake, a port receives from anyone
    - no guarantees: packets can arrive…
      - …out of order :-O , …not at all :-O , …in multiple copies :-O

Nagles’s algorithm

caching?
no, thank you

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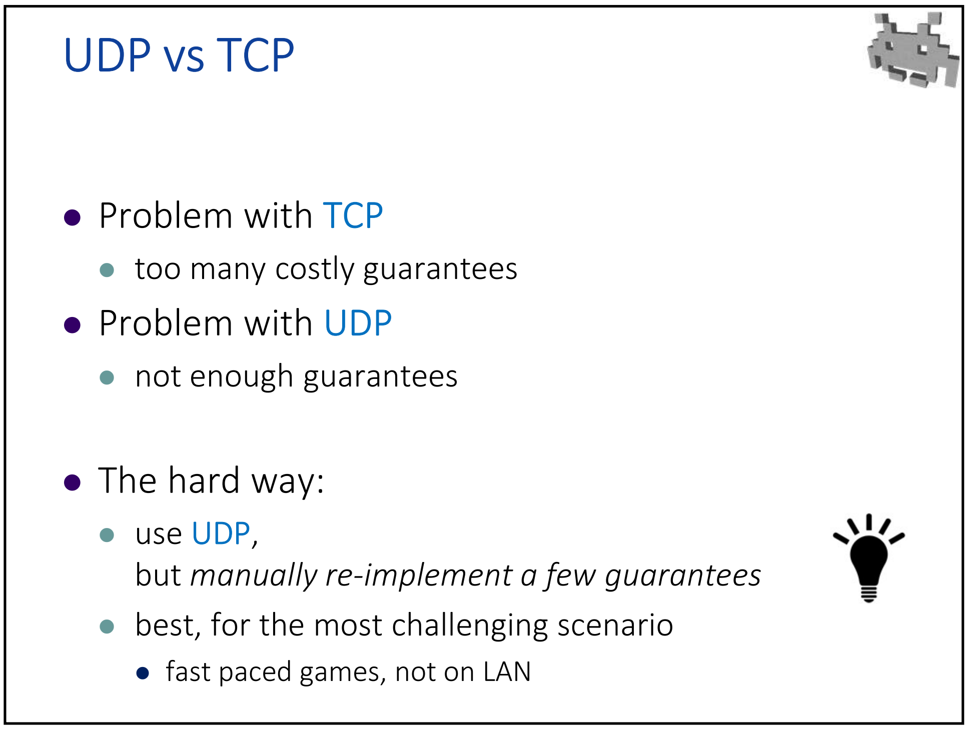

UDP vs TCP

- Problem with TCP
  - too many costly guarantees
- Problem with UDP
  - not enough guarantees
- The hard way:
  - use UDP,
    but *manually re-implement a few guarantees*
  - best, for the most challenging scenario
    - fast paced games, not on LAN

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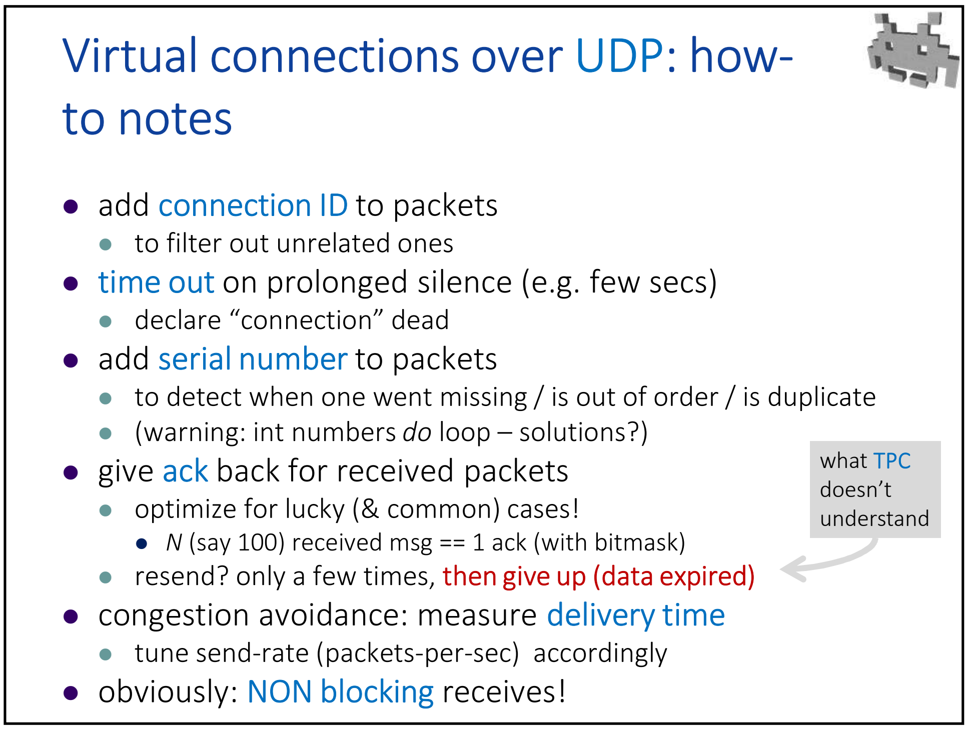

Virtual connections over UDP: how-to notes

- add connection ID to packets
  - to filter out unrelated ones
- time out on prolonged silence (e.g. few secs)
  - declare “connection” dead
- add serial number to packets
  - to detect when one went missing / is out of order / is duplicate
  - (warning: int numbers *do* loop – solutions?)
- give ack back for received packets
  - optimize for lucky (& common) cases!
    - *N* (say 100) received msg == 1 ack (with bitmask)
  - resend? only a few times, then give up (data expired)
- congestion avoidance: measure delivery time
  - tune send-rate (packets-per-sec) accordingly
- obviously: NON blocking receives!

what TPC doesn’t understand

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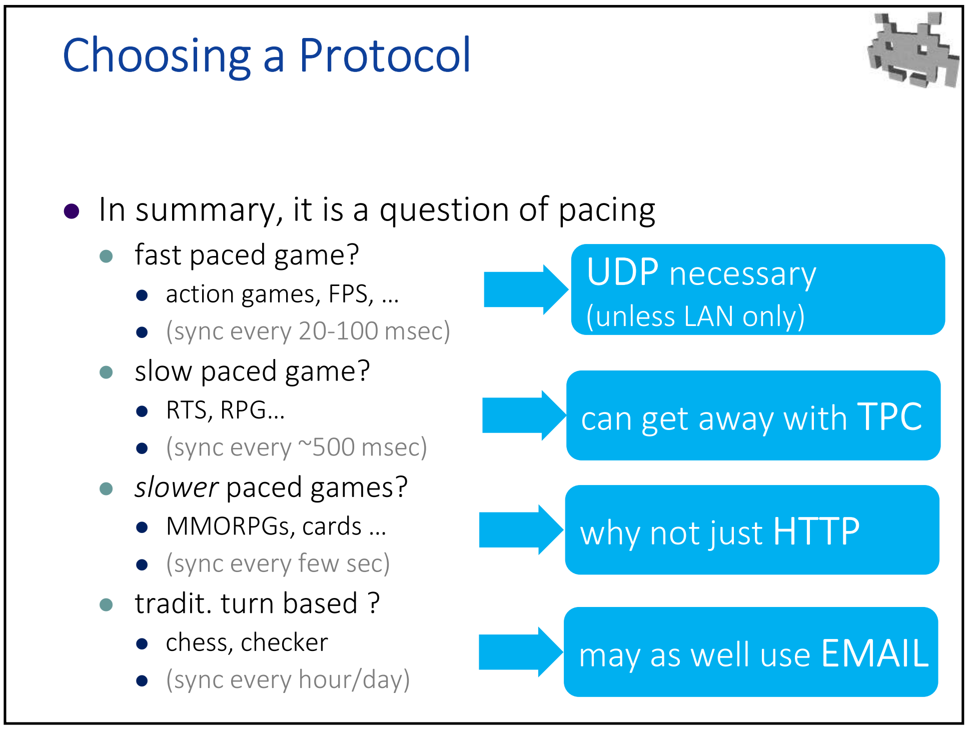

Choosing a Protocol

- In summary, it is a question of pacing
  - fast paced game?
    - action games, FPS, …
    - (sync every 20-100 msec)
  - slow paced game?
    - RTS, RPG…
    - (sync every ~500 msec)
  - *slower* paced games?
    - MMORPGs, cards …
    - (sync every few sec)
  - tradit. turn based ?
    - chess, checker
    - (sync every hour/day)

UDP necessary (unless LAN only)

can get away with TPC

why not just HTTP

may as well use EMAIL

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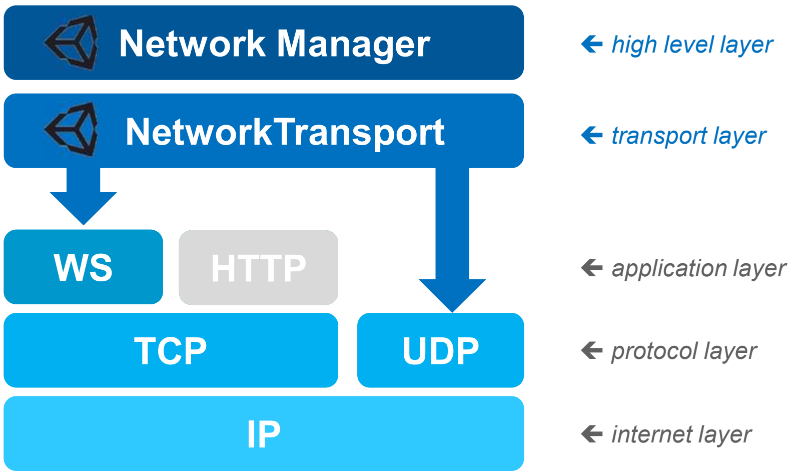
In Unity:



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In Unity:

- Low level: **`Transport Layer`**
  - Builds up guarantees over UDP (connections)
  - Easy to use as TCP, but optimized for games
    - see how-to listabove
  - Can work over WS instead UDP (hiding the differences)
    - WS needs be used for web / WebGL games
- Hi level: **`Network Manager`**
  - presets network connectivity
  - standard “client hosted” games
    - (server is also a player)
  - controls shared state of the game
  - deals with clients
  - sends remote commands

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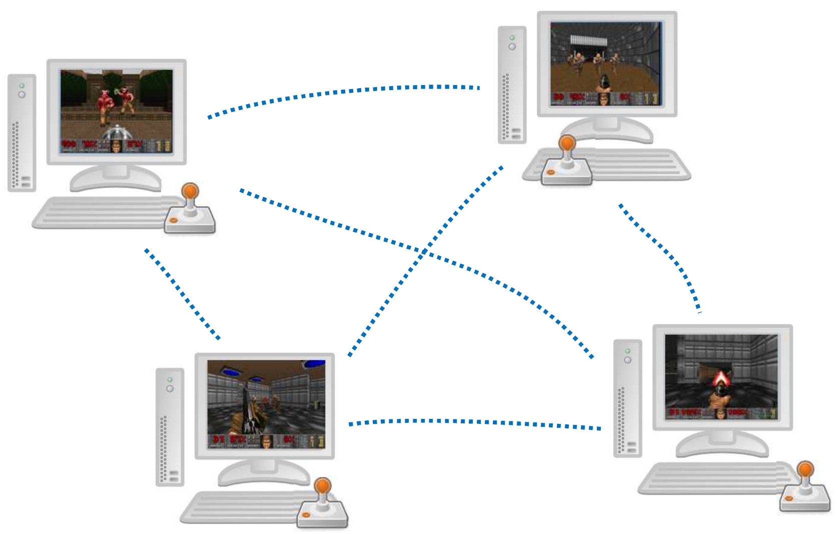
Network structure: Peer-to-Peer



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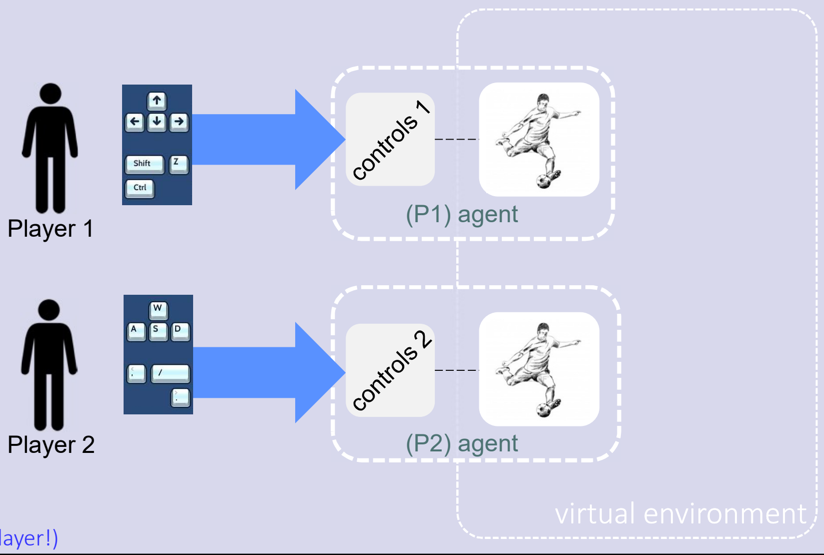
Controls and Agent

(an useful abstraction)



(local multiplayer!)

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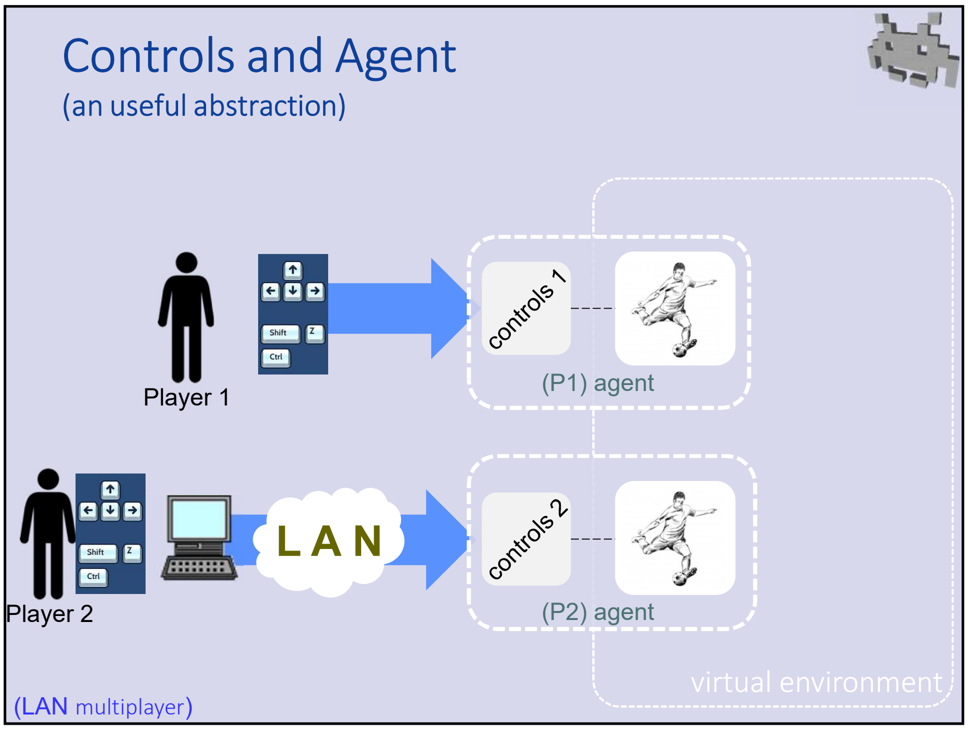

Controls and Agent

(an useful abstraction)

(LAN multiplayer)

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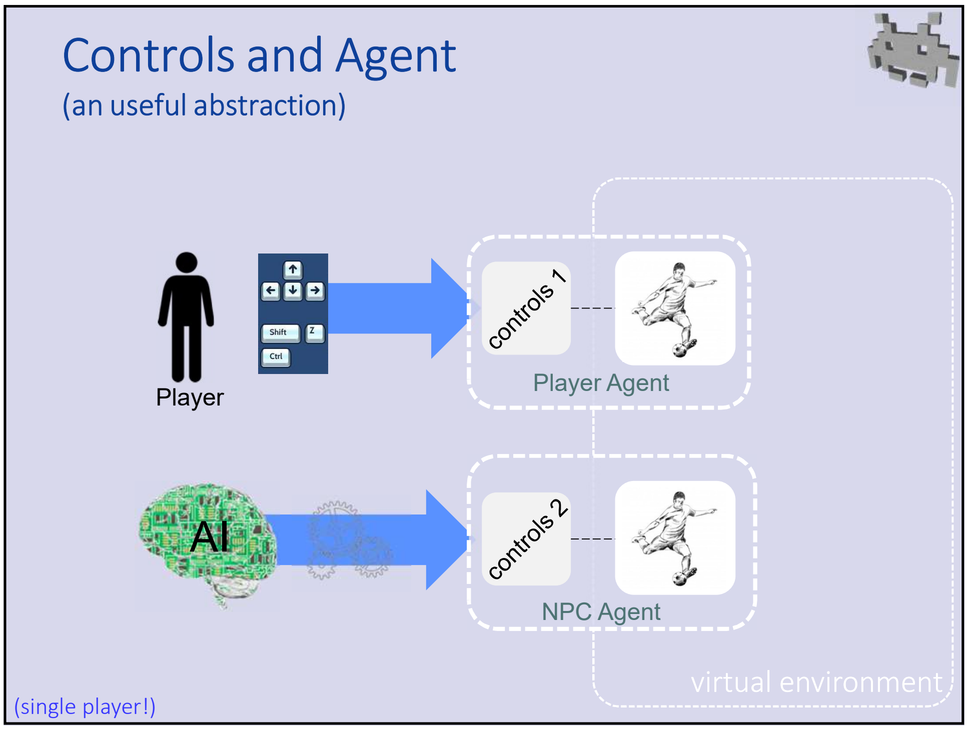

Controls and Agent

(an useful abstraction)

(single player!)

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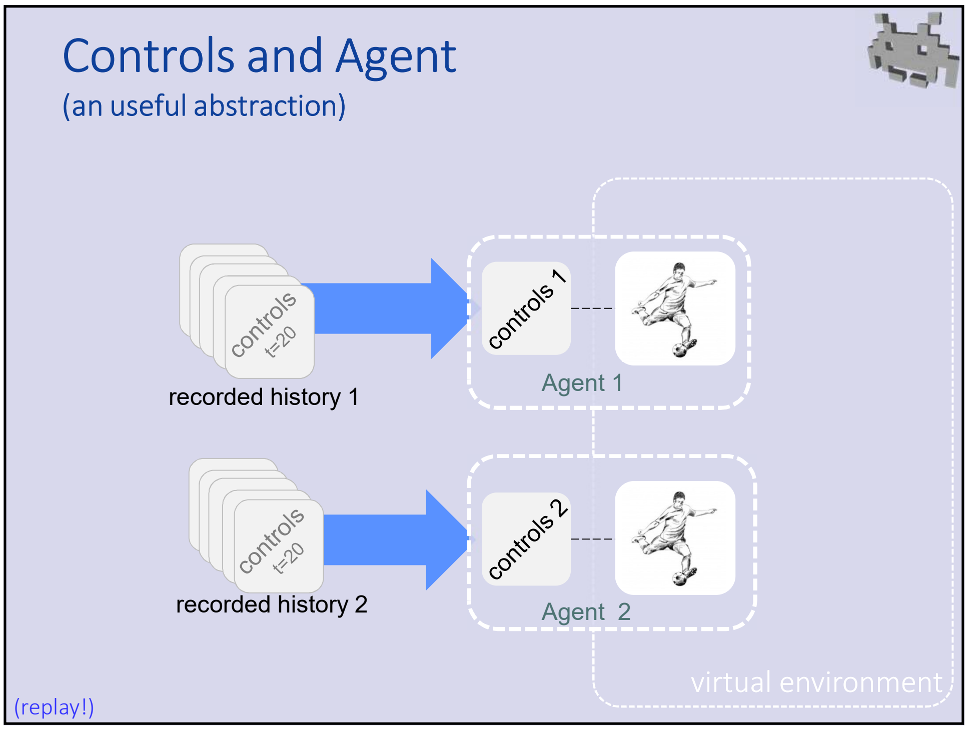

Controls and Agent

(an useful abstraction)

(replay!)

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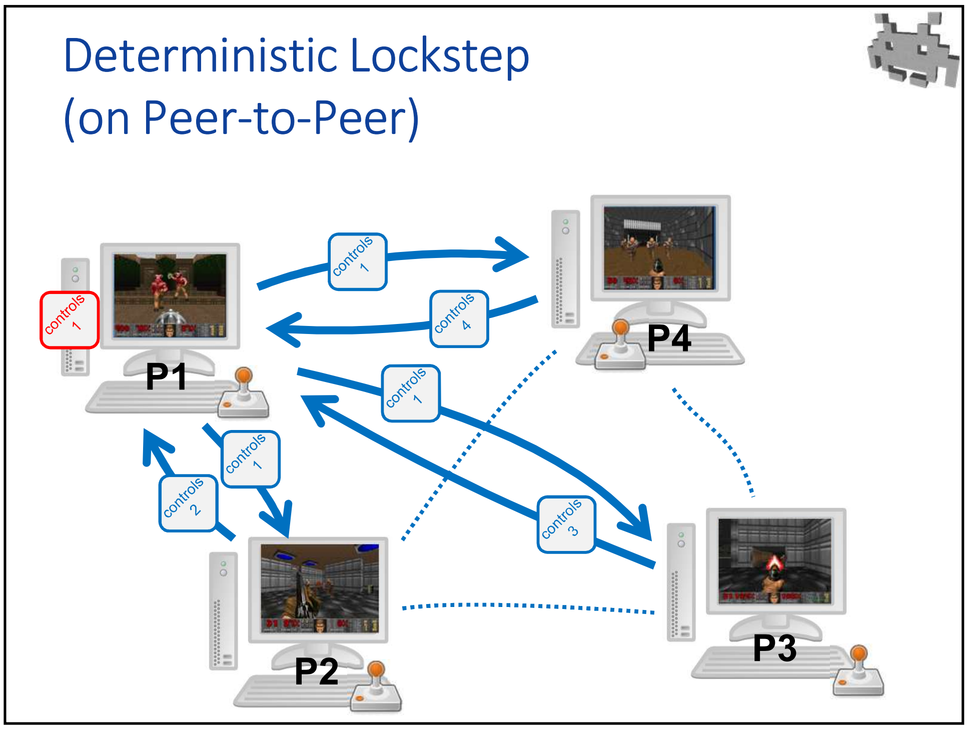

Deterministic Lockstep (on Peer-to-Peer)

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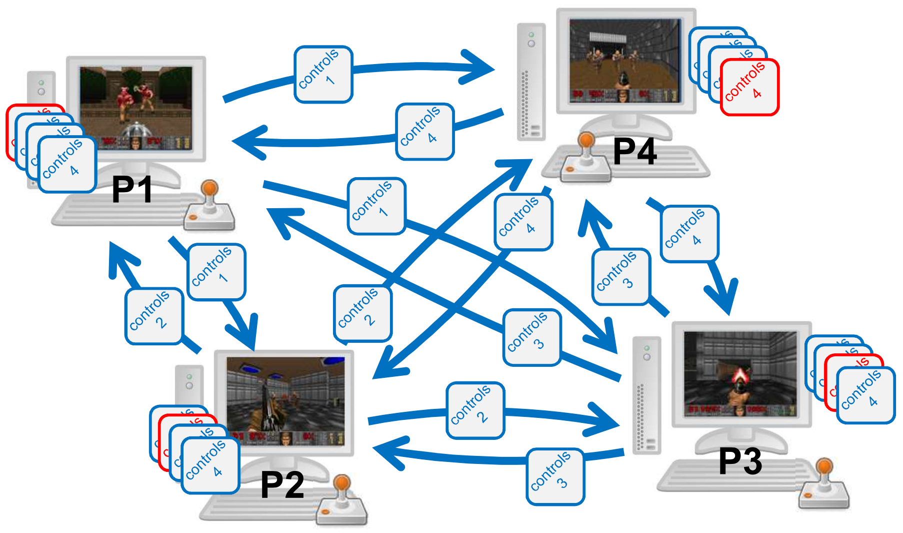
Deterministic Lockstep
(on Peer-to-Peer)



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Deterministic Lockstep
(on Peer-to-Peer)

- Game evolution = sequence of "turns"
  - e.g. physics steps (fixed *dt* !)
- Each node sends its current *controls* (inputs)
  - to everybody else
- After all controls are received,
  each node computes its own evolution
  - deterministically:
    same input → same result

even if
independently computed

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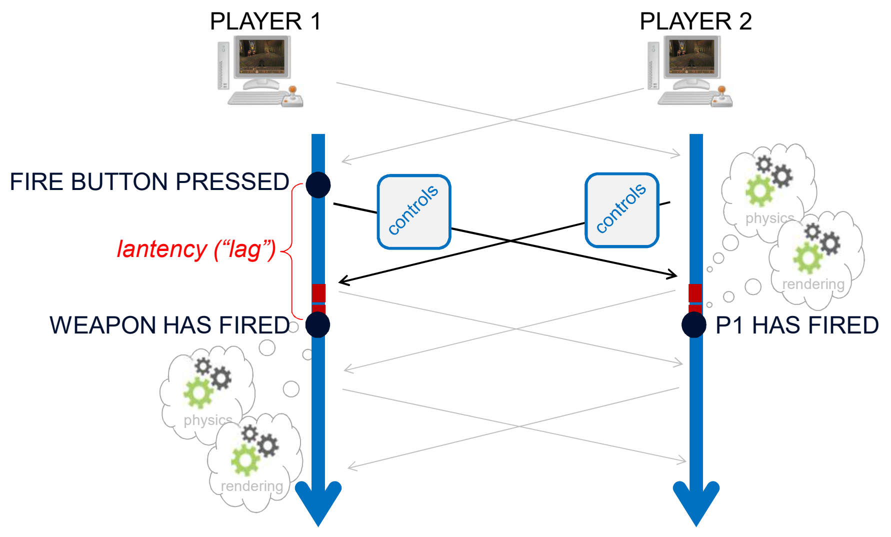
Deterministic Lockstep (on peer-to-peer network)



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Deterministic Lockstep: the good

- elegant and simple! ☺
- minimal bandwidth needed
  - only sent data = controls
    - compact! (e.g. a bitmask)
  - does not depend on complexity of virtual environment
- cheating: inherently limited
  - but a few ways to cheat are still possible, e.g.:
    - aimbots (unlawful assist from AI)
    - x-rays (unlawful reveal of info to player)
- mixes well with:
  - non-cheating AI, replays, player performance recording…
- can use simple TCP connections
  - because we need 0% packet loss anyway (but…)

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Deterministic Lockstep:
can as well use TPC instead of UDP ?

- why yes:
  - TPC is so simple!
    - takes care of everything
  - works well, when no packet loss
    - (with loss, we need resend it anyway: let TPC do that)
  - makes little sense to use UDP and then…
    try to re-implement all TPC over it
  - at the beginning of dev,
    UDP is a (premature) optimization
- why not:
  - to degrade better with lost packets
  - e.g.: use redundancy – instead of resend-on-failure
    - controls are small: send 100+ controls in every packet
    - keep resending until ack received

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Deterministic Lockstep

Starcraft Blizzard 1998-2015

- Actually used, e.g., on:
  - RTS
    - controls = orders
      - can be fairly complex
      - but game status =
        much more complex
  - *first generation* FPS
    - controls =
      [gaze dir + key status]

…why not anymore?

Command and Conquer
EA / Westmany et al
1995..2012

Age of Empires
Ensemble Studios et al,
1998..2015

Doom ID-soft, 1998

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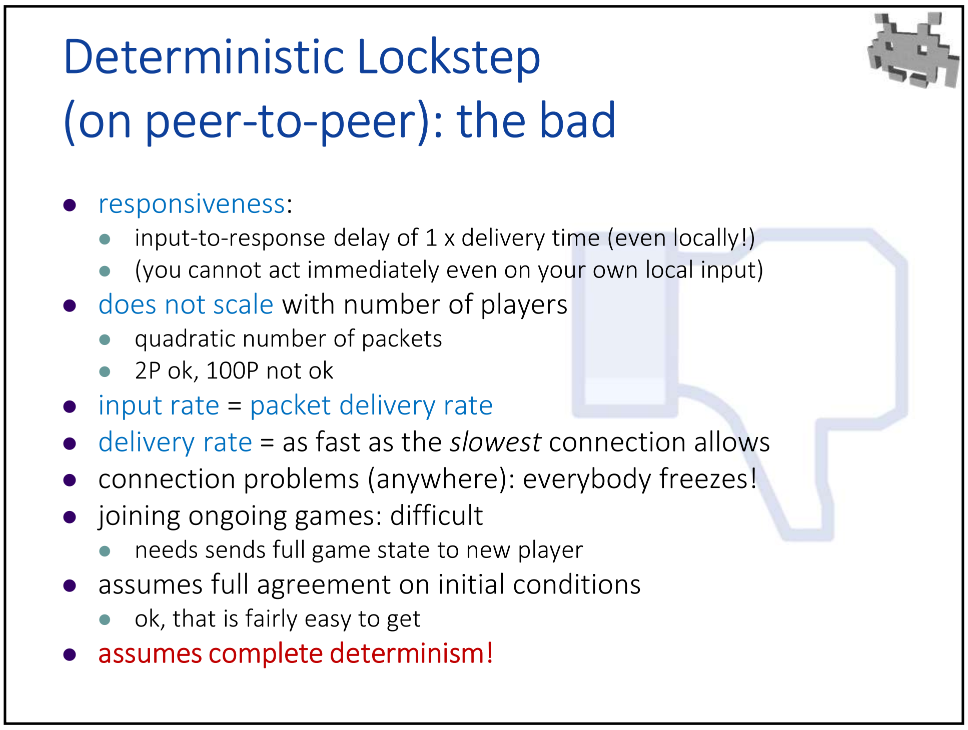

Deterministic Lockstep (on peer-to-peer): the bad

- responsiveness:
  - input-to-response delay of 1 x delivery time (even locally!)
  - (you cannot act immediately even on your own local input)
- does not scale with number of players
  - quadratic number of packets
  - 2P ok, 100P not ok
- input rate = packet delivery rate
- delivery rate = as fast as the *slowest* connection allows
- connection problems (anywhere): everybody freezes!
- joining ongoing games: difficult
  - needs sends full game state to new player
- assumes full agreement on initial conditions
  - ok, that is fairly easy to get
- assumes complete determinism!

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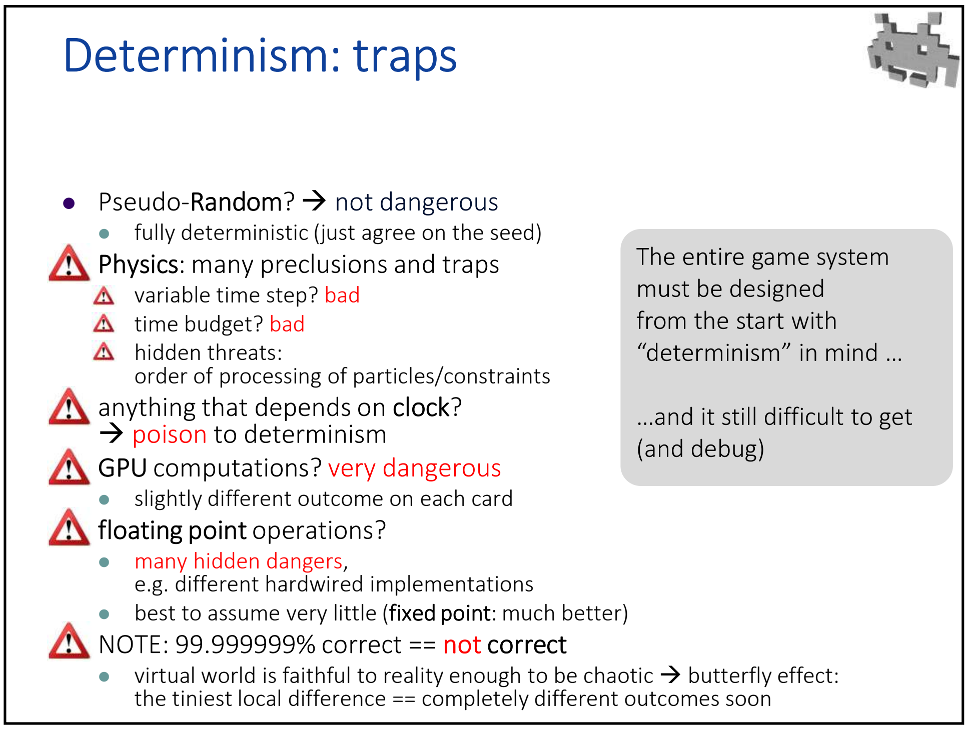

Determinism: traps

- Pseudo-**Random**? → not dangerous
  - fully deterministic (just agree on the seed)
- ⚠ **Physics**: many preclusions and traps
  - ⚠ variable time step? bad
  - ⚠ time budget? bad
  - ⚠ hidden threats:
    order of processing of particles/constraints
- ⚠ anything that depends on **clock**?
  → poison to determinism
- ⚠ **GPU** computations? very dangerous
  - slightly different outcome on each card
- ⚠ **floating point** operations?
  - many hidden dangers,
    e.g. different hardwired implementations
  - best to assume very little (**fixed point**: much better)
- ⚠ NOTE: 99.999999% correct == not **correct**
  - virtual world is faithful to reality enough to be chaotic → butterfly effect:
    the tiniest local difference == completely different outcomes soon

The entire game system must be designed from the start with "determinism" in mind …

…and it still difficult to get (and debug)

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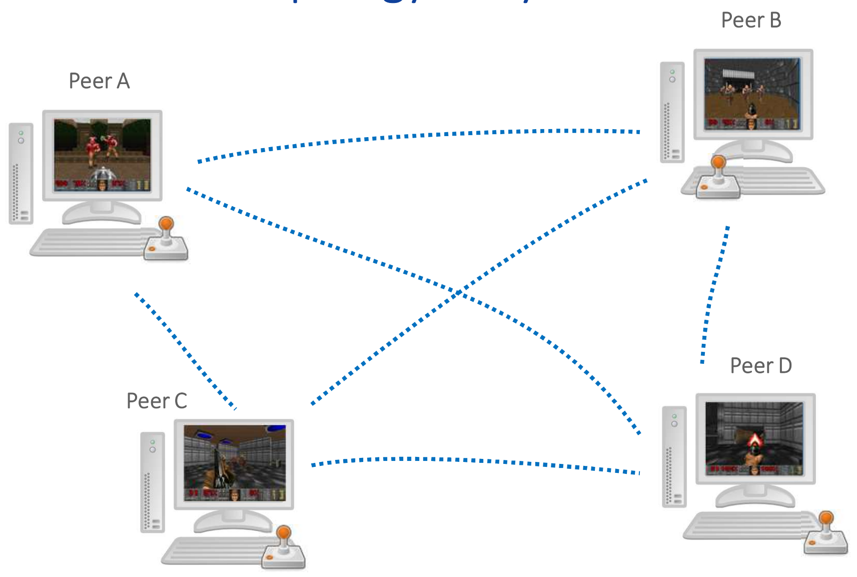
Peer-to-Peer
on network topology: fully connected



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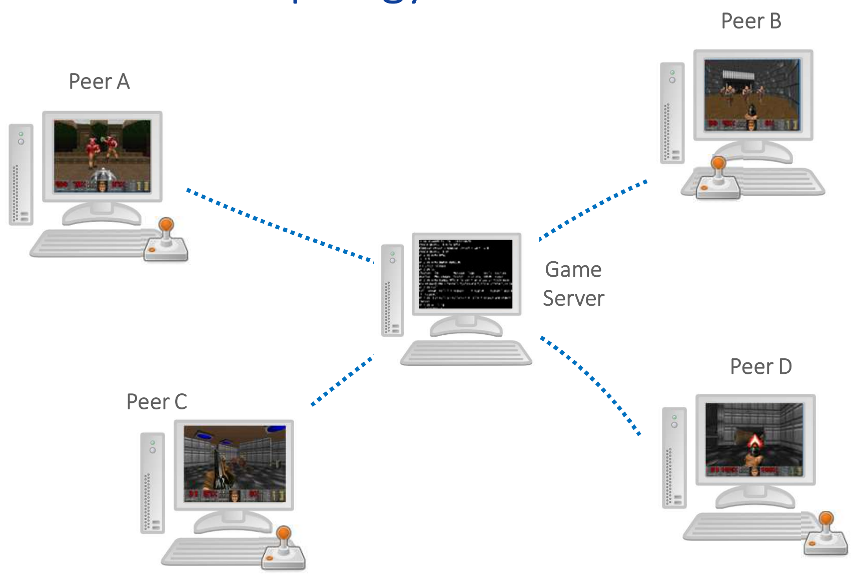
Client / Server
on network topology: star



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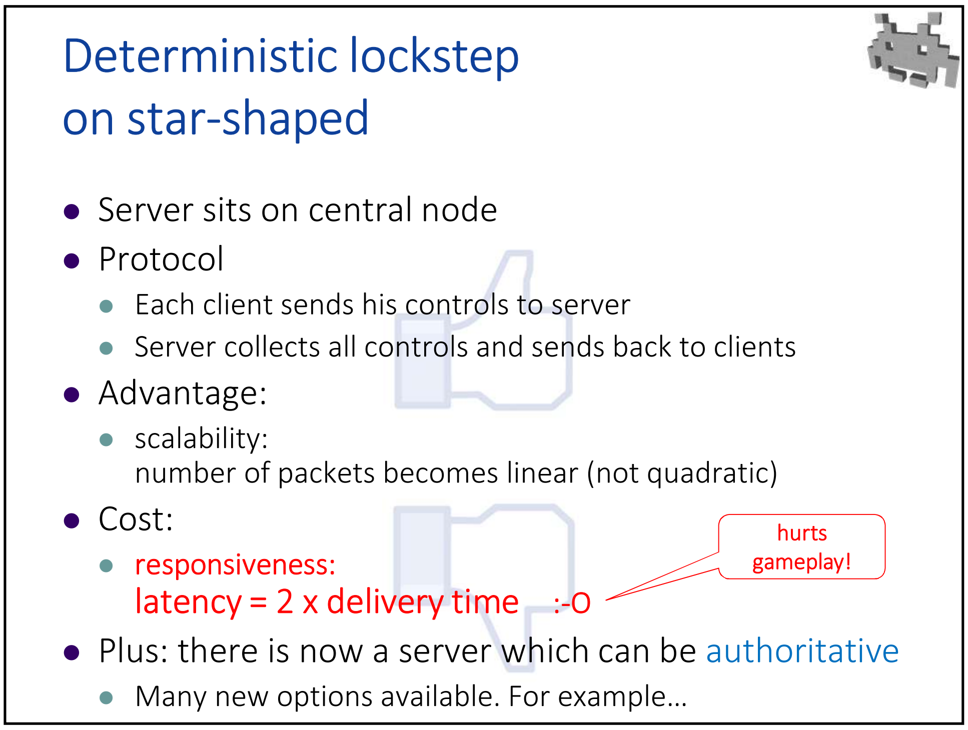

Deterministic lockstep on star-shaped

- Server sits on central node
- Protocol
  - Each client sends his controls to server
  - Server collects all controls and sends back to clients
- Advantage:
  - scalability:
    number of packets becomes linear (not quadratic)
- Cost:
  - responsiveness:
    latency = 2 x delivery time :-O

hurts gameplay!

- Plus: there is now a server which can be authoritative
  - Many new options available. For example…

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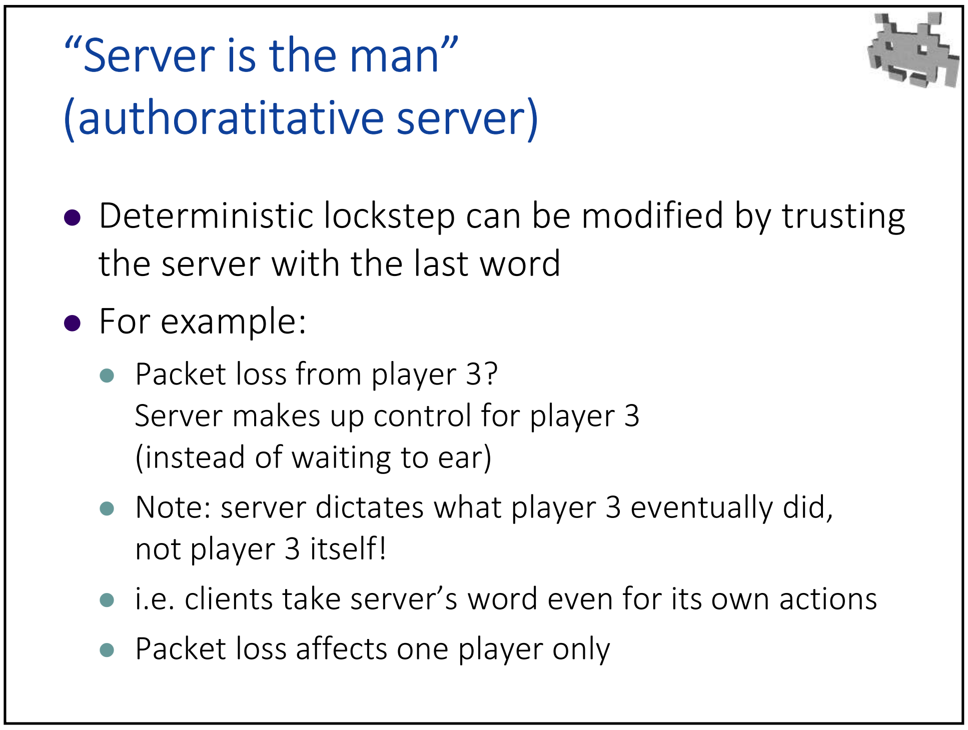

"Server is the man" (authoratitative server)

- Deterministic lockstep can be modified by trusting the server with the last word
- For example:
  - Packet loss from player 3?
    Server makes up control for player 3
    (instead of waiting to ear)
  - Note: server dictates what player 3 eventually did, not player 3 itself!
  - i.e. clients take server's word even for its own actions
  - Packet loss affects one player only

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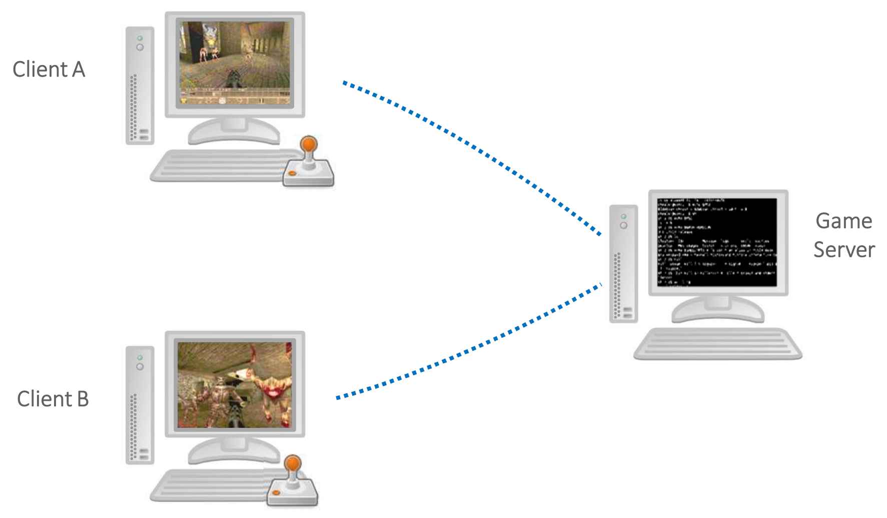
Client-Server



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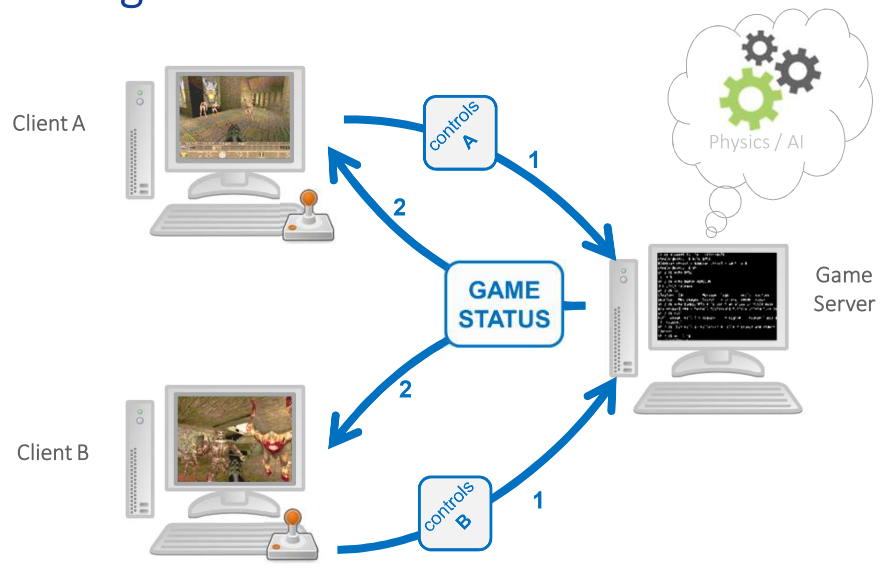
"Game-Status Snapshots" paradigm



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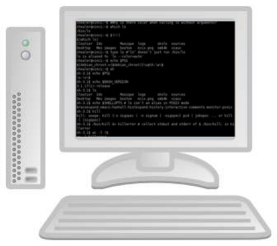
Game-Status Snapshots

- Client:
  - just a remote visualizer of the current status
    - status is "read only"
  - (+ remote input collector)
- Server:
  - computation of the evolving status
    - (including physics)
  - it's where the "real game" runs



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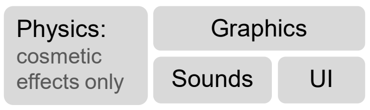
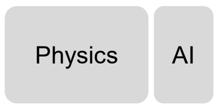
Game-Status Snapshots

- Client:
  - connected: to server only
  - captures input
  - sends controls
  - receives game status
    - or relevant portions of it
  - renders it
    - using all relevant assets
- Server
  - connected: to all players
  - receives all controls
    - (missing? doesn't matter)
  - updates game status
    - physical simulations, etc
  - sends current status
    - to all





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Game-Status Snapshots

- the gains:
  - determinism: no longer needs be assumed
  - joining ongoing games: trivial now
  - packet loss: bearable (hurts the player *only*)
    - to profit: UDP
  - slower connection: bearable (affects that player *only*)
- the losses:
  - packet size: a lot bigger!
    - optimizations, to counter this:
      - compress world status
      - send to each client only the portions which interest its player
  - responsiveness:
    from input to effect = delivery time :-(
    from input to visual = 2 x delivery time :-O

hurts gameplay!

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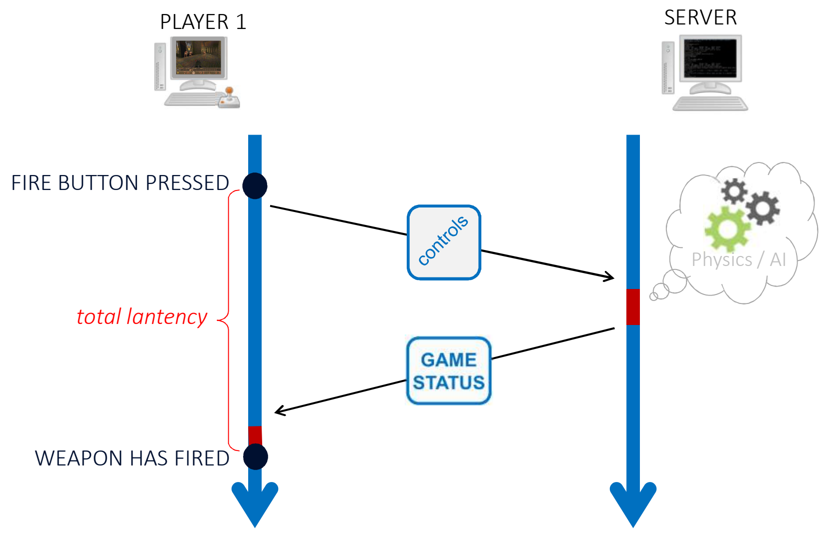
Game-Status Snapshots



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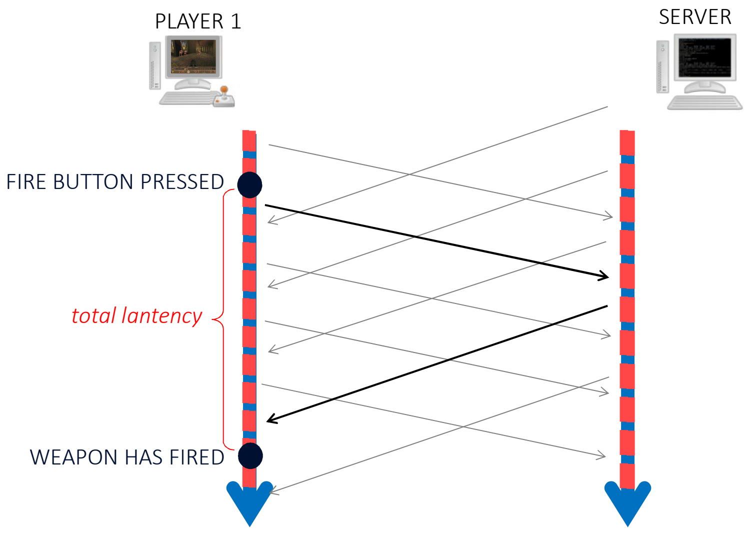
Game-Status Snapshots



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Game-Status Snapshots: with Interpolation: the idea

- World "Snapshot" contains:
  - data needed for 3D rendering: (position-orientation of objects, plus anything else needed)
- Problem:
  - large snapshot size! (even with optimizations)
  - ==> few FPS (in the physical simulation)
  - ==> "jerky" animations
- Solution 1: client-side interpolation
  - client keeps last two snapshots in memory
    - last received one + the previous one
  - interpolates between them,
    - client lags behind server by even more!
  - gain: smoothness (high FPS with low packet - rate)
  - loss: responsiveness (increased latency) oh noes!

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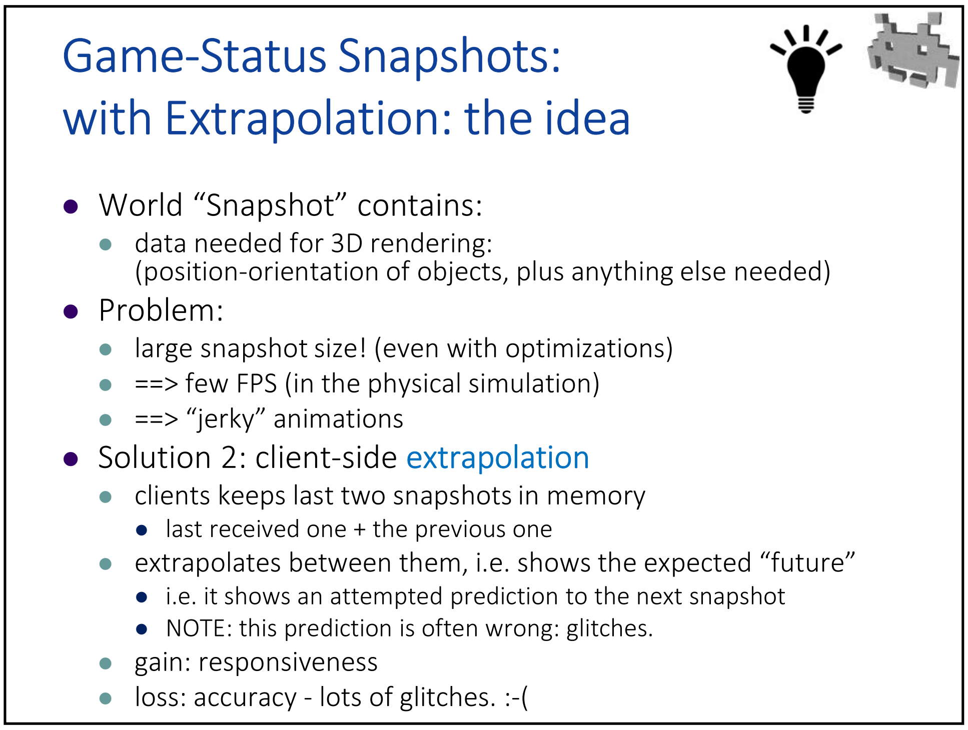

Game-Status Snapshots: with Extrapolation: the idea

- World “Snapshot” contains:
  - data needed for 3D rendering:
    (position-orientation of objects, plus anything else needed)
- Problem:
  - large snapshot size! (even with optimizations)
  - ==> few FPS (in the physical simulation)
  - ==> “jerky” animations
- Solution 2: client-side extrapolation
  - clients keeps last two snapshots in memory
    - last received one + the previous one
  - extrapolates between them, i.e. shows the expected “future”
    - i.e. it shows an attempted prediction to the next snapshot
    - NOTE: this prediction is often wrong: glitches.
  - gain: responsiveness
  - loss: accuracy - lots of glitches. :-(

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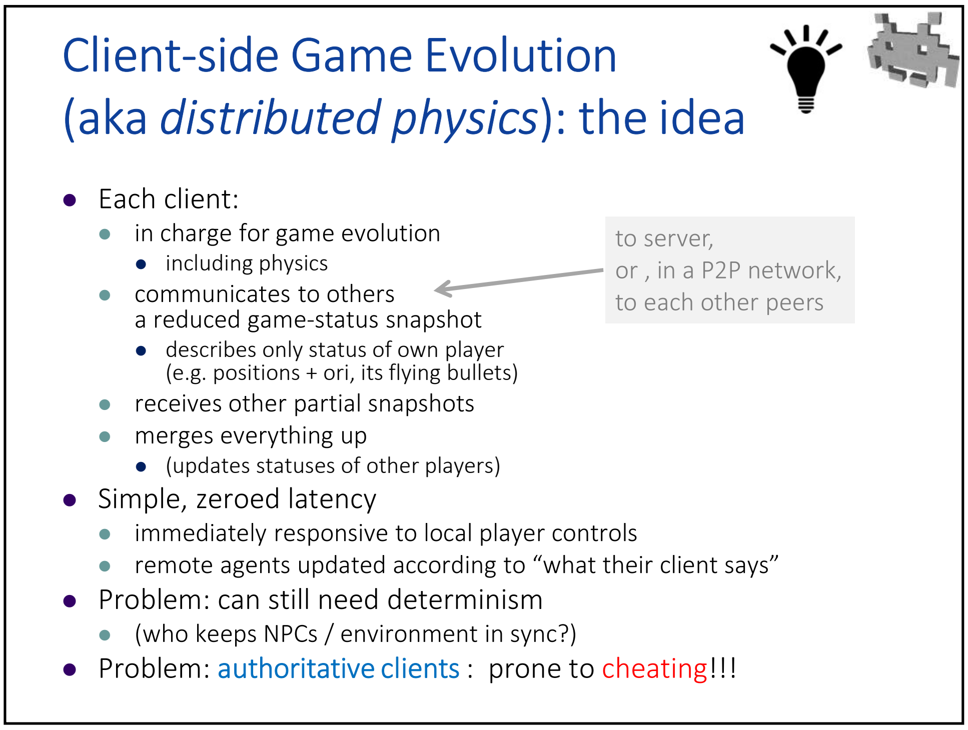

Client-side Game Evolution (aka *distributed physics*): the idea

- Each client:
  - in charge for game evolution
    - including physics
  - communicates to others
    a reduced game-status snapshot
    - describes only status of own player
      (e.g. positions + ori, its flying bullets)
  - receives other partial snapshots
  - merges everything up
    - (updates statuses of other players)
- Simple, zeroed latency
  - immediately responsive to local player controls
  - remote agents updated according to “what their client says”
- Problem: can still need determinism
  - (who keeps NPCs / environment in sync?)
- Problem: authoritative clients : prone to cheating!!!

to server,
or , in a P2P network,
to each other peers

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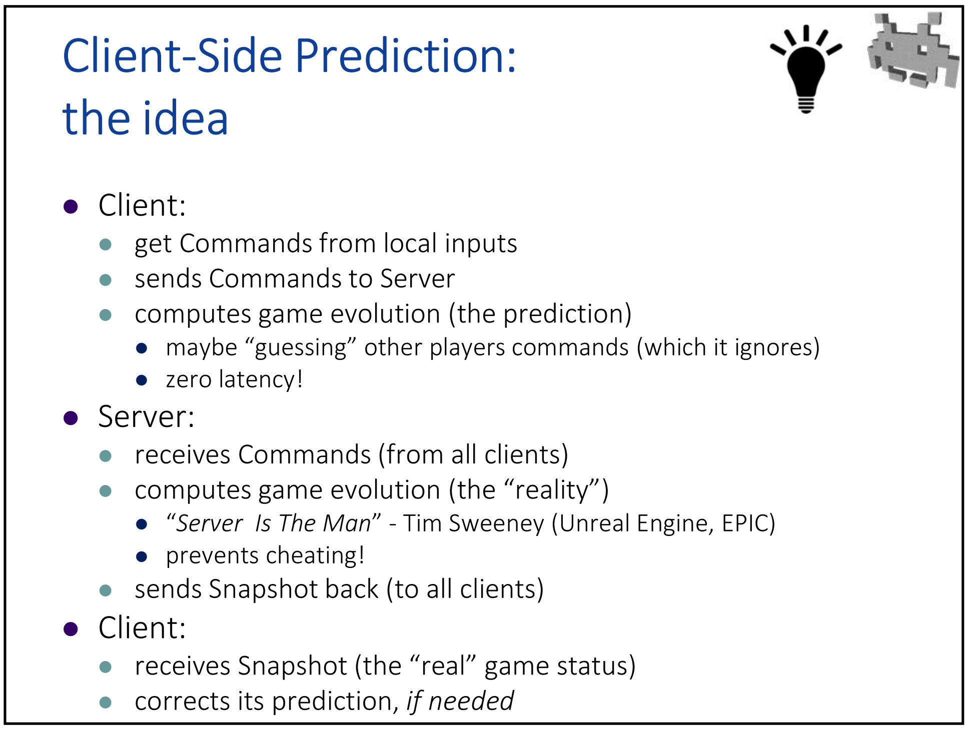

Client-Side Prediction: the idea

- Client:
  - get Commands from local inputs
  - sends Commands to Server
  - computes game evolution (the prediction)
    - maybe "guessing" other players commands (which it ignores)
    - zero latency!
- Server:
  - receives Commands (from all clients)
  - computes game evolution (the "reality")
    - *"Server Is The Man"* - Tim Sweeney (Unreal Engine, EPIC)
    - prevents cheating!
  - sends Snapshot back (to all clients)
- Client:
  - receives Snapshot (the "real" game status)
  - corrects its prediction, *if needed*

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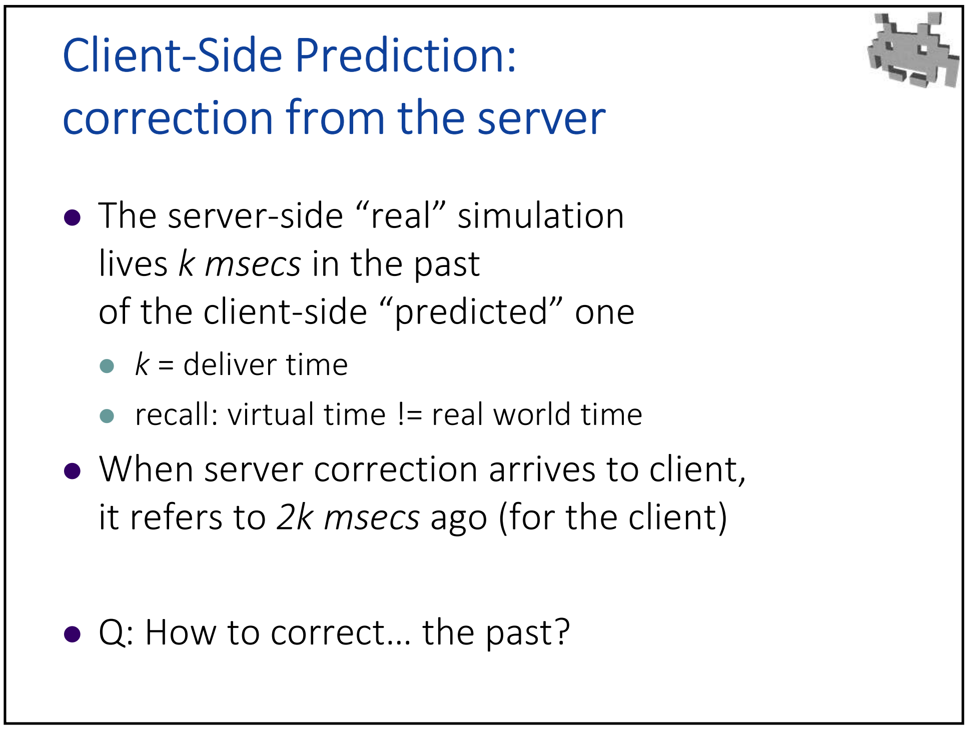

Client-Side Prediction: correction from the server

- The server-side "real" simulation lives *k msecs* in the past of the client-side "predicted" one
  - *k* = deliver time
  - recall: virtual time != real world time
- When server correction arrives to client, it refers to *2k msecs* ago (for the client)
- Q: How to correct... the past?

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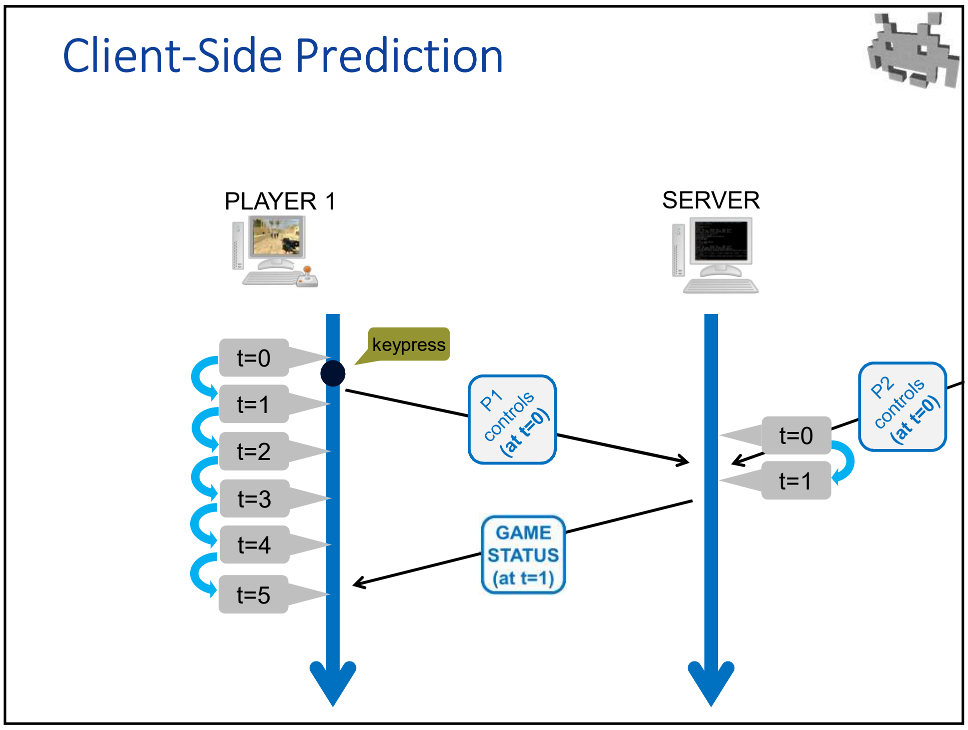

Client-Side Prediction

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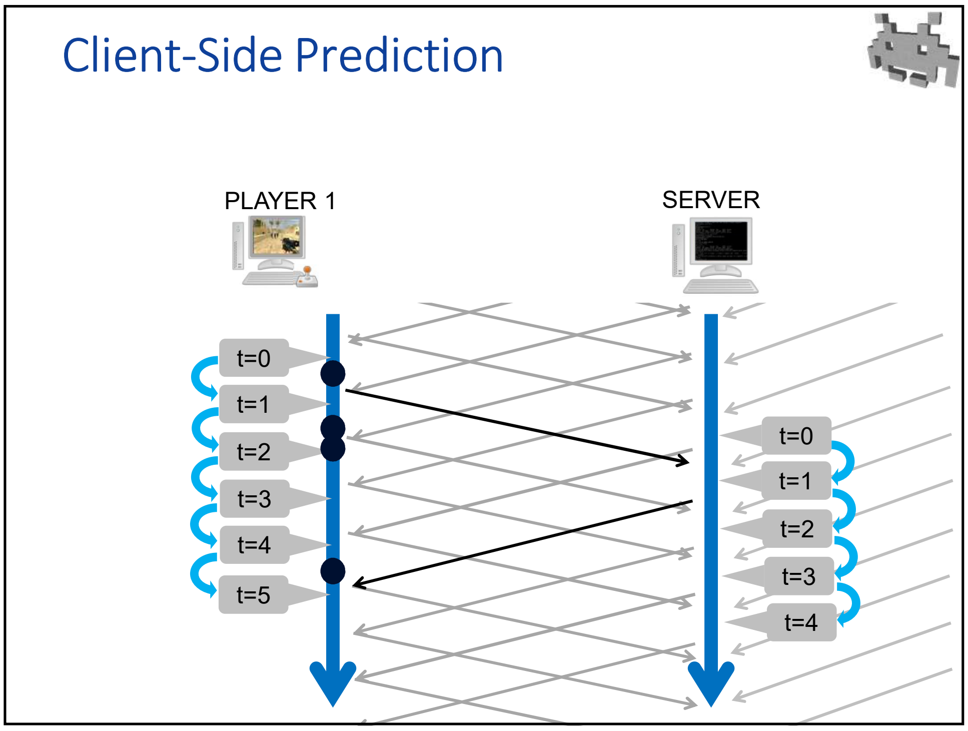

Client-Side Prediction

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Client-Side Prediction: correction from the server

- Q: How to correct… the past?
- A:
  - keep last *N* statuses in memory
    - including own controls
  - “real” status (the correction) of the past arrives from server
  - compare it with corresponding past status:
    - matches?
      nothing to do
    - mismatches?
      discard frame and following ones,
      rerun simulation to present (reusing stored controls)

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Re-running physical simulation

- Just need to catch up with the present
- Physics and AI only… at full speed
  - no graphics, no sound rendering,
    no cosmetic particle system…
- Can use larger dt if necessary
  - Compromises accuracy
- Must reuse same controls of own player
  - Which are also cached
- Note: player is never shown these intermediate steps. Only the final result
- Glitch when going from current present to different present

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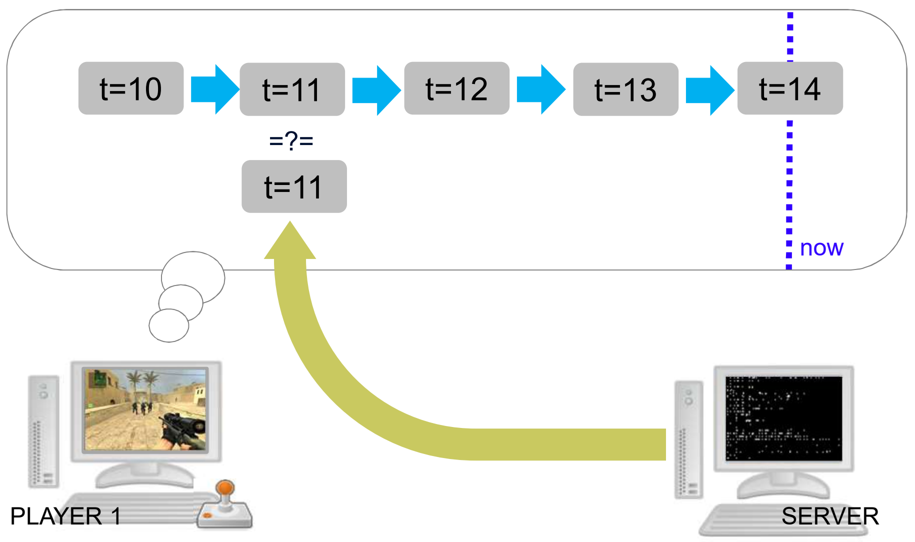
Client-Side Prediction: correction in the past



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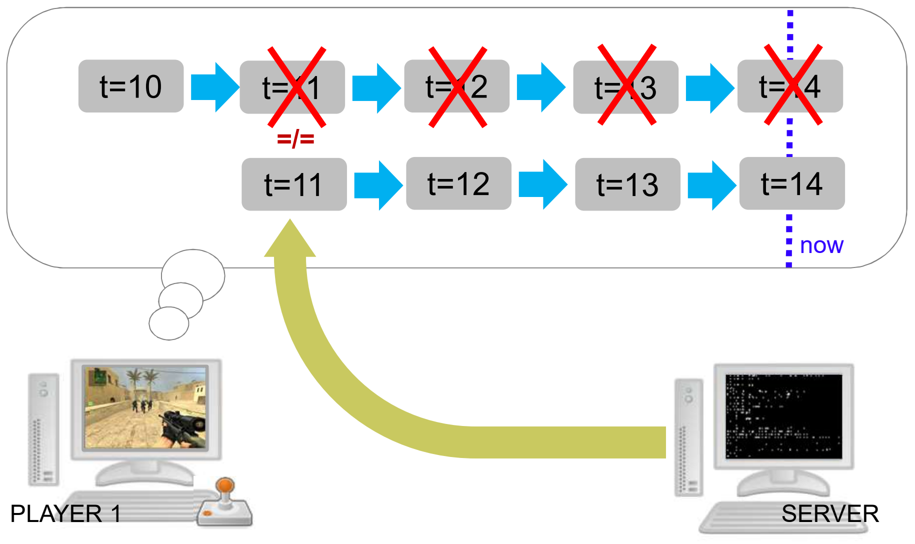
Client-Side Prediction: correction in the past



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Client-Side Prediction: what causes mispredictions?

- Lack of determinism
  - e.g. physics was approximated – “soft real time”
  - see above for more possible causes of this
  - (minor/rare issue)
- Didn’t account that *own* controls were not received by server (in time)
  - server: “actually, you didn’t jump, back then”
  - authoritative server – server *defines* the truth, (even when the client is in a better position to know)
  - (minor/rare issue)
- Didn’t account for other players’ controls
  - (the most common issue)
- Note: none of the above breaks the game
  - it just causes minor / temporary glitches ☺

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Client-Side Prediction: optimizations 1/2

- reduce snapshots size
  (==> to increase packet frequency)
  - partial snapshots: refresh more often the parts which are most likely to be predicted wrong / or which changed
  - drastic space reductions!
  - but make sure that every part is eventually refreshed

- reduce correction overload
  (==> so to make corrections quicker)
  - partial physic steps:
    update only the parts affected by the error

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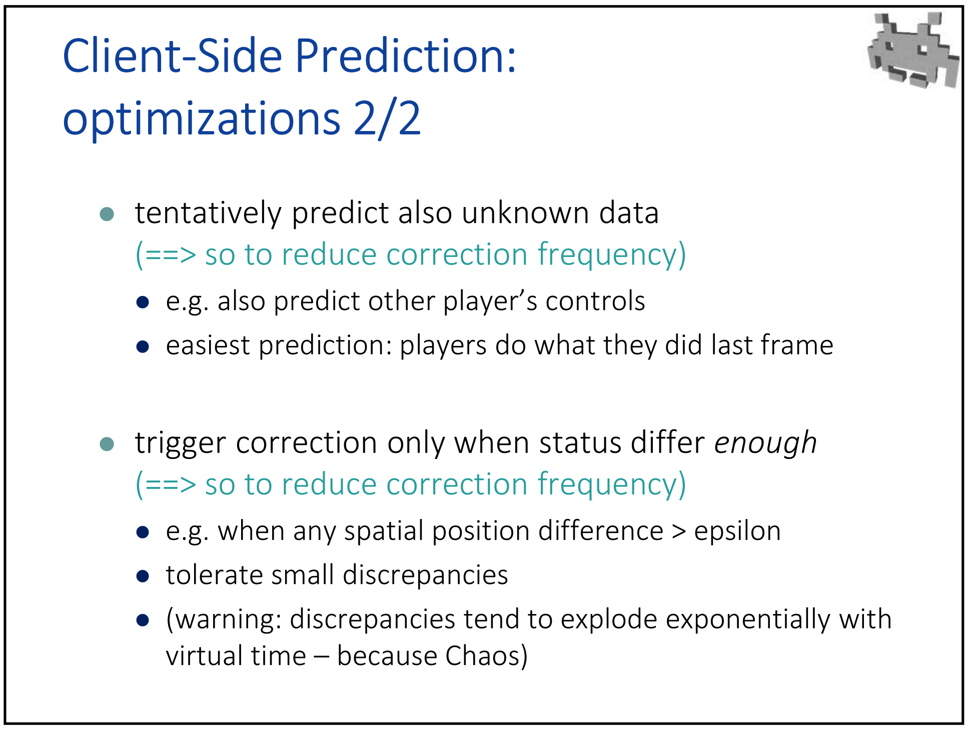

Client-Side Prediction: optimizations 2/2

- tentatively predict also unknown data
  (==> so to reduce correction frequency)
  - e.g. also predict other player's controls
  - easiest prediction: players do what they did last frame
- trigger correction only when status differ *enough*
  (==> so to reduce correction frequency)
  - e.g. when any spatial position difference > epsilon
  - tolerate small discrepancies
  - (warning: discrepancies tend to explode exponentially with virtual time – because Chaos)

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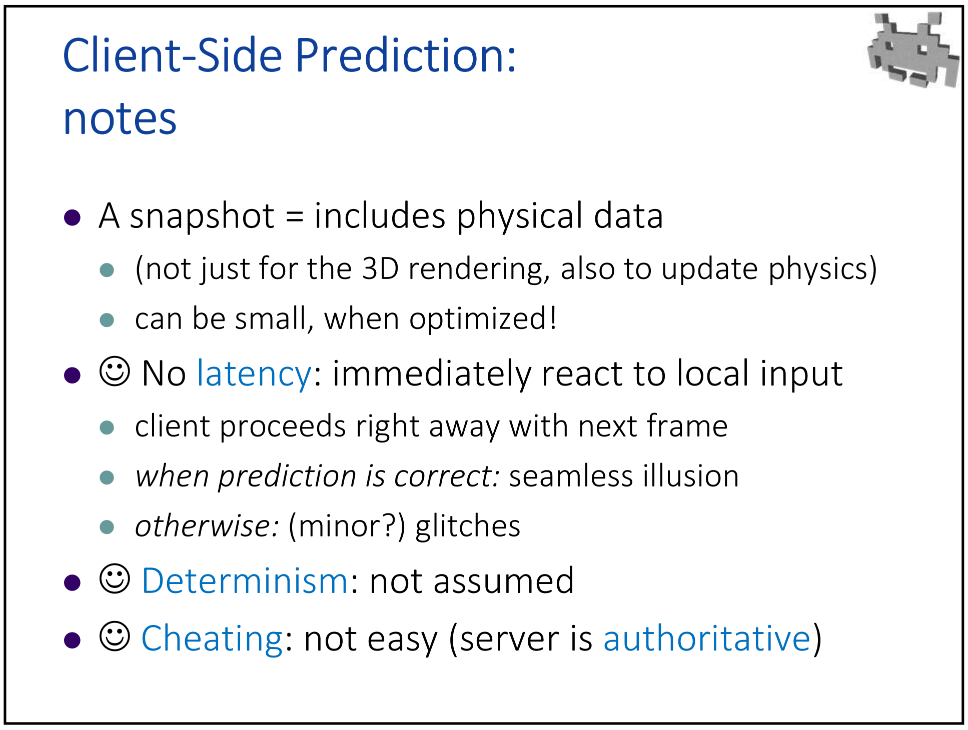

Client-Side Prediction: notes

- A snapshot = includes physical data
  - (not just for the 3D rendering, also to update physics)
  - can be small, when optimized!
- ☺ No latency: immediately react to local input
  - client proceeds right away with next frame
  - *when prediction is correct:* seamless illusion
  - *otherwise:* (minor?) glitches
- ☺ Determinism: not assumed
- ☺ Cheating: not easy (server is authoritative)

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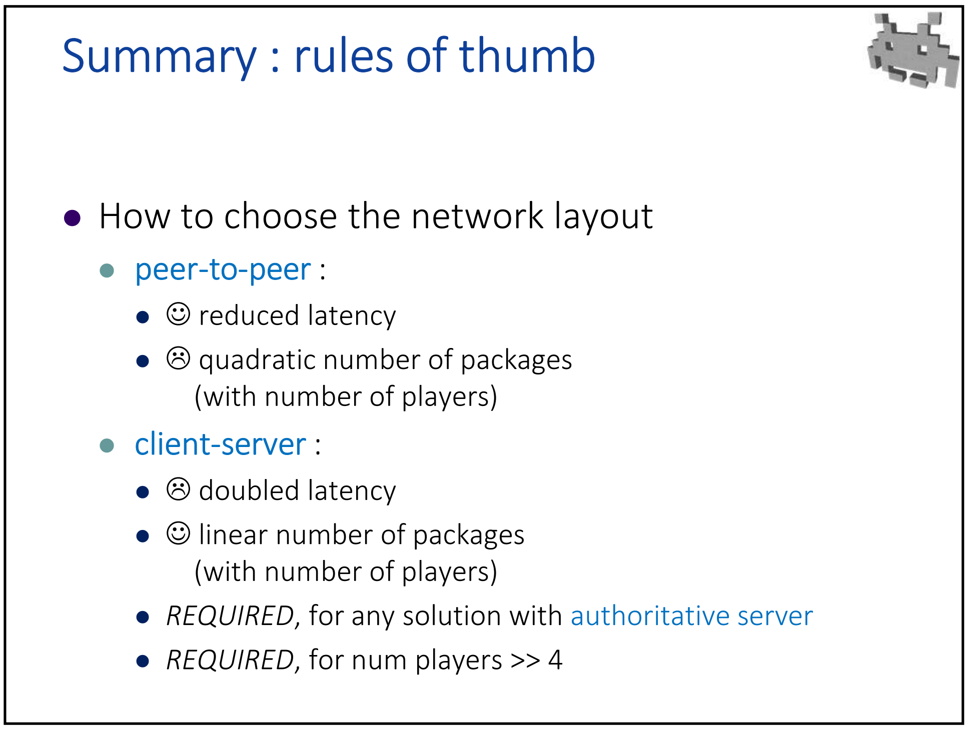

Summary : rules of thumb

- How to choose the network layout
  - peer-to-peer :
    - ☺ reduced latency
    - ☹ quadratic number of packages
      (with number of players)
  - client-server :
    - ☹ doubled latency
    - ☺ linear number of packages
      (with number of players)
    - *REQUIRED*, for any solution with authoritative server
    - *REQUIRED*, for num players >> 4

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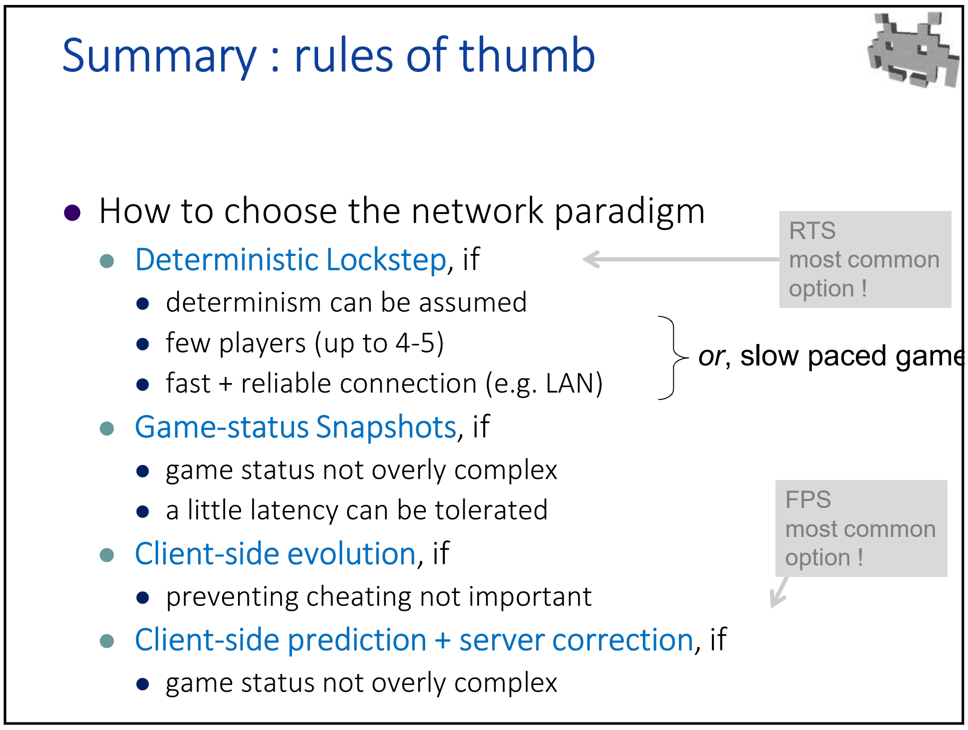

Summary : rules of thumb

- How to choose the network paradigm
  - Deterministic Lockstep, if
    - determinism can be assumed
    - few players (up to 4-5)
    - fast + reliable connection (e.g. LAN)
  - Game-status Snapshots, if
    - game status not overly complex
    - a little latency can be tolerated
  - Client-side evolution, if
    - preventing cheating not important
  - Client-side prediction + server correction, if
    - game status not overly complex

or, slow paced game

RTS
most common
option !

FPS
most common
option !

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Summary: classes of solutions

- Who computes game evolution? (incl. physics)
  - deterministic-lockstep : clients
    - there may be no server at all: peer-to-peer
    - independent computation, same result
  - game-status snapshots : server
    - clients are just visualizers
    - maybe with interpolation / extrapolation
  - (distributed physics : both clients and server)
    - clients in charge for own agent(s)
    - server in charge for env. / NPCs
  - client-side predictions : both clients and server
    - clients "predict" (just for local visualization purposes)
    - server "corrects" (it has the last word!)

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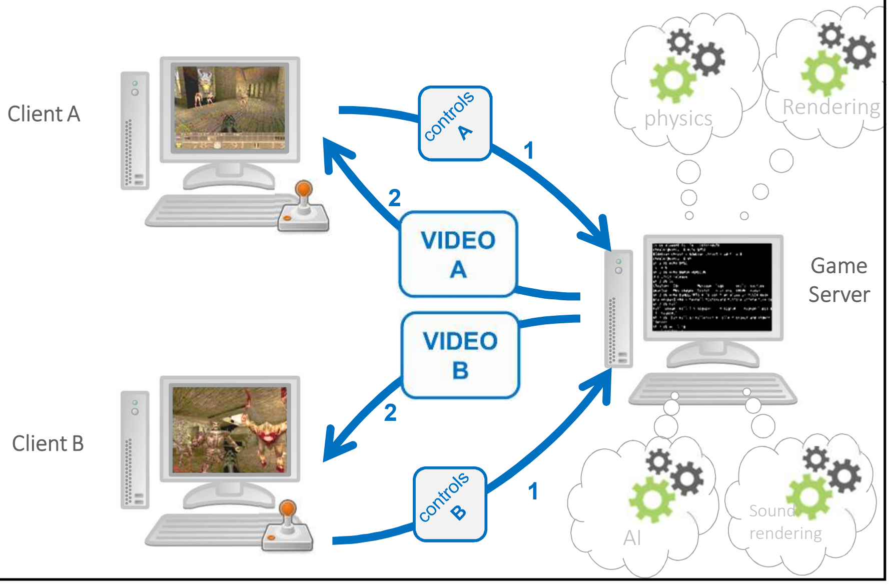
Cloud-gaming with video-streaming (aka game on demand)



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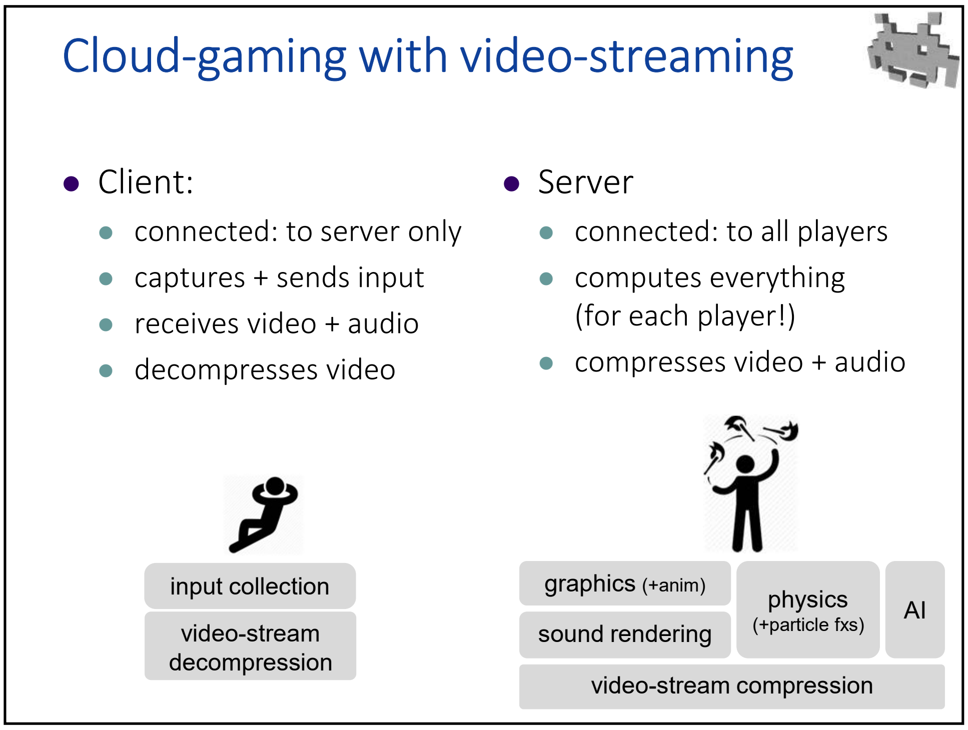

Cloud-gaming with video-streaming

- Client:
  - connected: to server only
  - captures + sends input
  - receives video + audio
  - decompresses video
- Server
  - connected: to all players
  - computes everything (for each player!)
  - compresses video + audio

input collection
video-stream decompression
graphics (+anim)
sound rendering
physics (+particle fxs)
AI
video-stream compression

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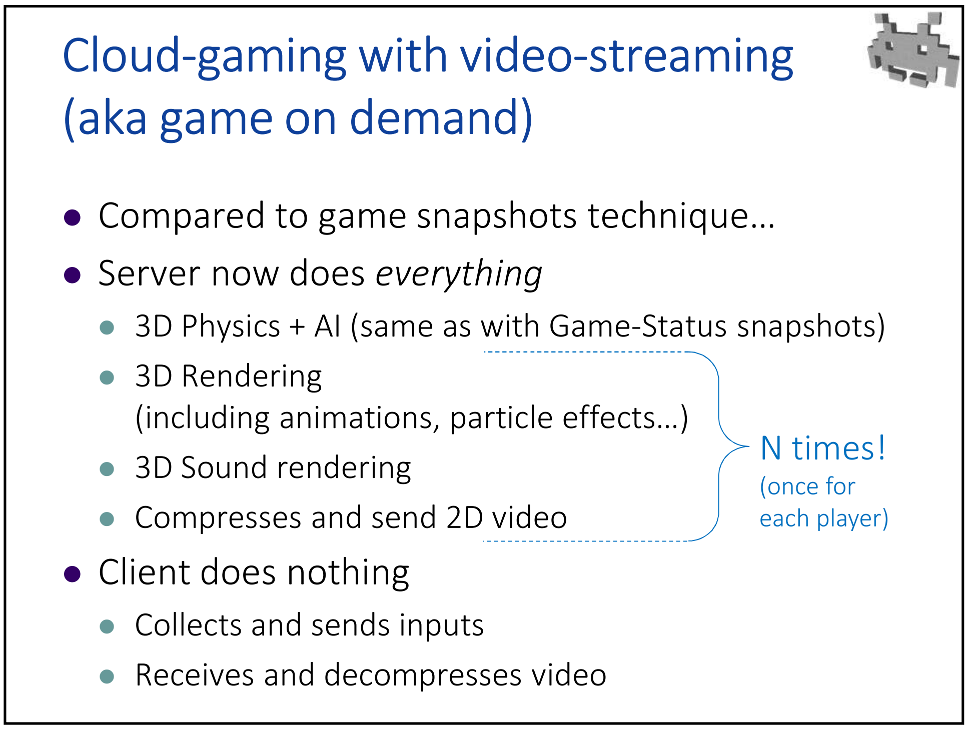

Cloud-gaming with video-streaming (aka game on demand)

- Compared to game snapshots technique…
- Server now does *everything*
  - 3D Physics + AI (same as with Game-Status snapshots)
  - 3D Rendering (including animations, particle effects…)
  - 3D Sound rendering
  - Compresses and send 2D video
- Client does nothing
  - Collects and sends inputs
  - Receives and decompresses video

N times! (once for each player)

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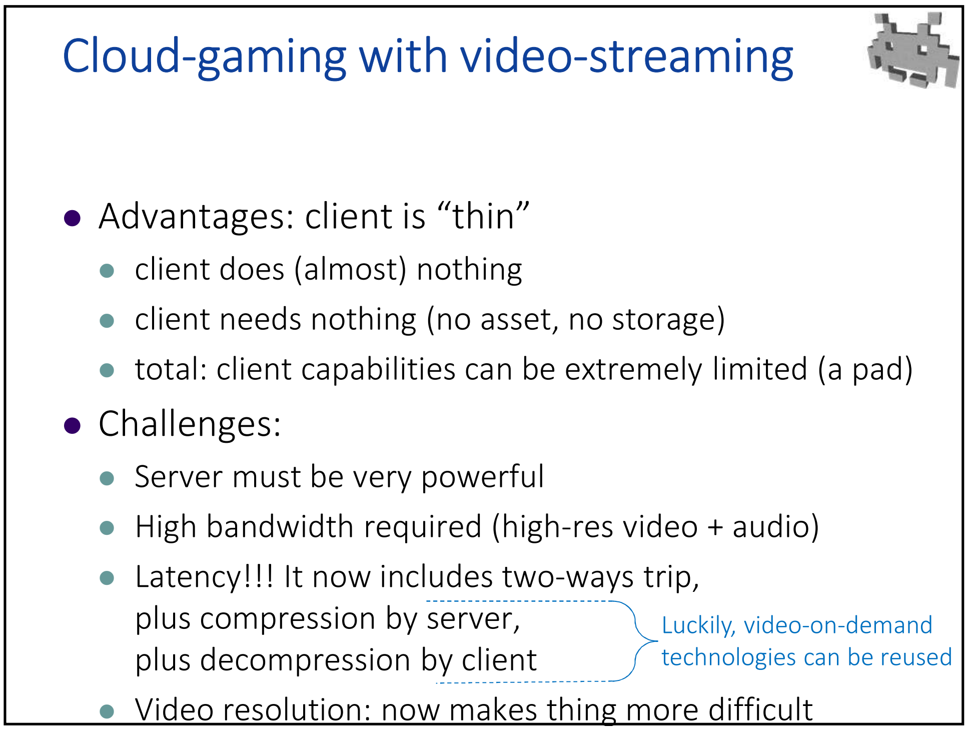

Cloud-gaming with video-streaming

- Advantages: client is “thin”
  - client does (almost) nothing
  - client needs nothing (no asset, no storage)
  - total: client capabilities can be extremely limited (a pad)
- Challenges:
  - Server must be very powerful
  - High bandwidth required (high-res video + audio)
  - Latency!!! It now includes two-ways trip,
    plus compression by server,
    plus decompression by client
    Luckily, video-on-demand technologies can be reused
  - Video resolution: now makes thing more difficult

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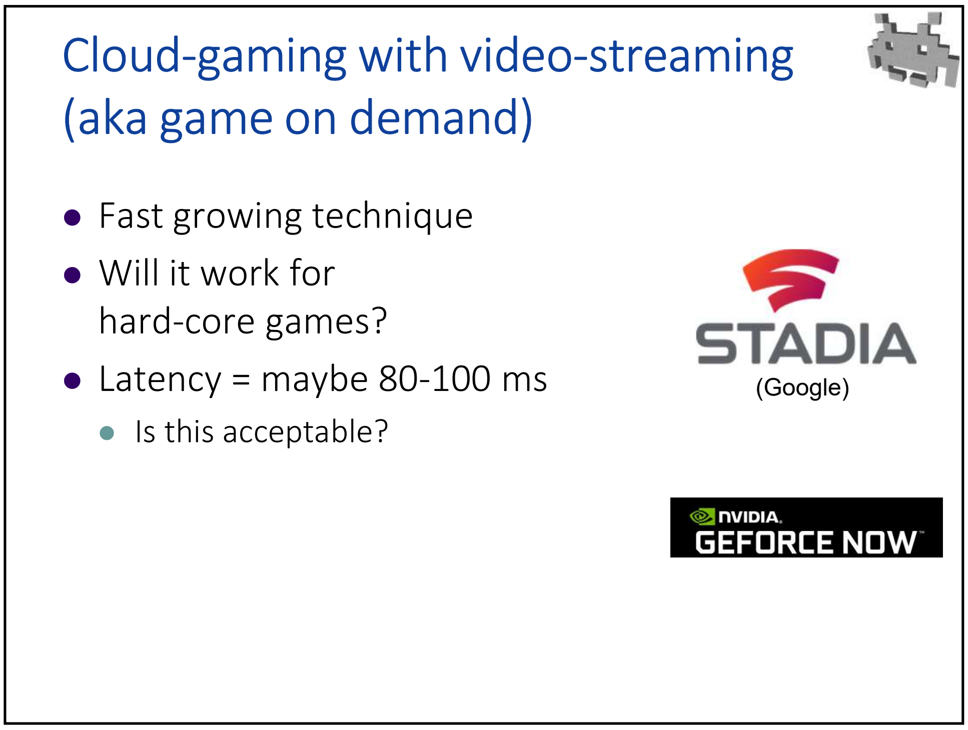

Cloud-gaming with video-streaming (aka game on demand)

- Fast growing technique
- Will it work for hard-core games?
- Latency = maybe 80-100 ms
  - Is this acceptable?

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