CS354P

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OVERVIEW: NETWORKING

NETWORKING IN GAMES

- Many games are networked -- even single-player experiences
- What sort of data are is being transmitted?
- Where does the data come from?
- How is the data being processed?

CS: GO

Final Fantasy XIV

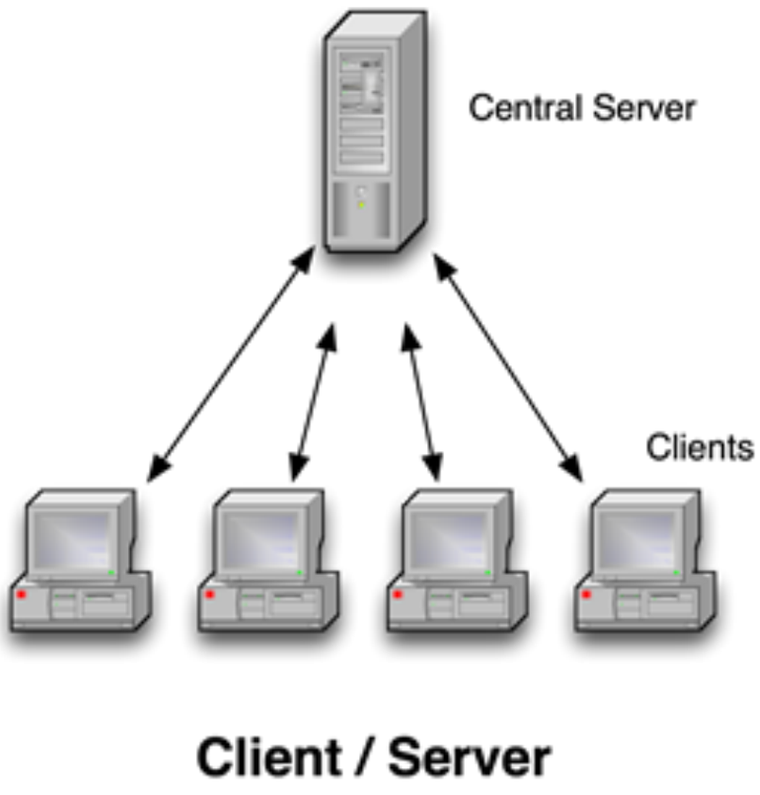
Death Stranding

PERSISTENT VS TRANSIENT WORLDS

- World data can either be generated per-session (transient) or stored between sessions (persistent)
  - Choice depends on type of game/ experience and studio's budget
- Transient games can have one of the players act as a host
- Persistent games require a dedicated server(s)

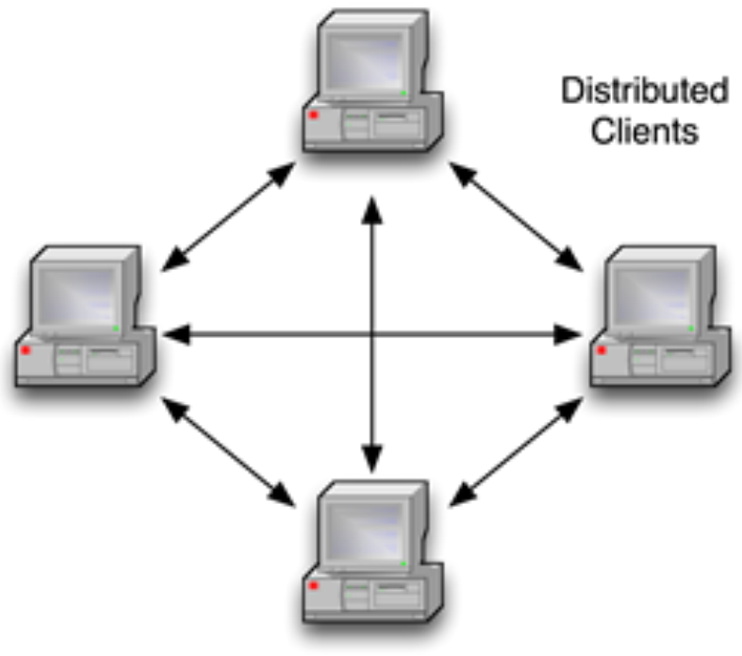
Crowfall

CLIENT-SERVER MODEL



- Common model for deciding how to distribute data in both persistent and transient worlds
- Server is the **authority** on game state
  - Decides what the clients see in the game
  - Determines what and how client actions can change the game state
- In transient games, the server can be the player's system that all clients connect to

PEER-TO-PEER (P2P) MODEL



- Model for deciding how to distribute data in transient worlds
- No one peer is the authority
  - Resource management distributed across peers
  - Each peer determines how other peers are influencing game state accordingly
- Useful in genres like fighting games where both peers have equal authority and games have limited world state

GAME SERVERS

- We will focus on client-server setups as they are more common in games
- In the client-server model, game servers manage final version of world state
- Several ways to manage this:
  - Perform all calculations on server
  - Perform some calculations on server and some on clients
  - Perform all calculations on client and allow server to determine “ground truth” from these calculations

PERFORMING ALL CALCULATIONS ON CLIENTS?

- Not a great idea
  - Too much security risk
  - All the overhead of a P2P network with none of the benefits
- Not really done in practice

PERFORMING ALL CALCULATIONS ON SERVER?

- At first glance, this is the safest and easiest way to manage game state
  - All of world state (including player information) is **replicated** from the server
    - i.e. Clients see a copied version of the current world state
  - When a client provides controller input, input is sent to server to be processed
  - Server performs actions based on valid input, updates its world state, then sends this updated data to all clients
- What problems arise from this setup?

LATENCY AND LAG

- Latency is the time it takes from starting to do something to finishing it
- Lag in user interaction is the latency from when a user provides input to the time they see the response
- Ideally we want to process user input every ~16ms (60Hz) or more
  - Worst case (i.e. consoles) we process input at a fixed rate of ~33ms (30Hz)
  - Assumes humans see at around 30Hz* ensuring good responsiveness even if the game frame is out of sync with our eye "frame"
- Handling player inputs on the server introduces *network latency* into the existing lag of user interaction
  - Will not be responsive

*This is a gross simplification of human vision but it works well enough in practice

HOW TO HANDLE PLAYER INPUT LATENCY?

- Allow client to perform latency-sensitive actions **autonomously**
- Action performed on client before being verified on the server
- If server and client agree, action is replicated to all other clients
- If server and client disagree, server adjusts client's world state to match the server state

UE5: CHARACTER MOVEMENT COMPONENT

- Uses three network roles:
  - **Autonomous Proxy** is character on owning client's machine
  - **Authority** is character on the server
  - **Simulated Proxy** is character on non-owning client machines
- Replication happens at 30Hz

AUTONOMOUS PROXY CHARACTER

- Locally controlled by owning player
- Runs `PerformMovement` locally to determine physical logic of character
  - Highly responsive with no network latency
- Stores movement data in `FSavedMove_Character` and queues these into `SavedMoves`
- Sends condensed version of data to server

AUTHORITY CHARACTER

- Updated by server when server receives `SavedMoves`
- Server checks updated position and orientation of character against the client's reported position and orientation
- If values match, server informs owning client their movement was valid
- If values do not match, server sends corrections to owning client to fix autonomous proxy's values
  - Autonomous proxy reproduces authority's movements and retraces steps based on `SavedMoves`
  - Autonomous proxy only removes moves from `SavedMoves` after movement is successfully resolved

SIMULATED PROXY CHARACTER

- Movement information is replicated from server
- Used for all characters, both AI (controlled on server) and players (autonomous proxies)
- Network smoothing used to clean up motion on client's end
  - Interpolates between current location and target location using `SmoothClientPosition`

HOW DO MACHINES COMMUNICATE?

RPCS

- Remote Procedure Calls
- Allows for the execution of code in a different address space as though it were a local call
- Can use for both remote and local calls
- Message-passing mechanism hidden
- Remote and local calls can be handled based on role

USING NETWORKING IN UNREAL

- Must include "`Net/UnrealNetwork.h`"
- Include `Replicated` keyword in `UPROPERTY` to replicate an Actor's property
- Set `bReplicates` in the replicating Actor to true
- Implement function `GetLifetimeReplicatedProps(TArray<FLifetimeProperty>& OutLifetimeProps)` in replicating Actor
  - Add `DOREPLIFETIME(AMyActor, PropertyName);` for each property being replicated
- UE5 handles replicated pointers using GUIDs (Globally Unique Identifiers)
  - Server assigns `FNetworkGUID` value and clients are notified

REPNOTIFY

- Allows execution of a function when a variable's value changes
  - Each property specifies the function it will call
- Specify with `ReplicatedUsing = OnRep_PropertyName` instead of `Replicated` in `UPROPERTY`
- Create `OnRep_PropertyName()` function that will be called
  - This will specify what should happen when the value is changed
  - Can update local (non-replicated) assets using these

UE5 NETWORKING FUNCTIONS

- `UFUNCTION` must specify who is executing the function and how reliable the function needs to be
  - `Server` only executes the code on the server
  - `Client` only executes the code on the owning client
  - `NetMulticast` executed on the server will also execute on all clients
- Additional options here: https://docs.unrealengine.com/5.2/en-US/function-specifiers/
- Functions must use a `_Implementation` *thunk*
- `Server` must have specifier `WithValidation` and implement an additional `_Validate` function

NETWORKING FUNCTION EXAMPLE: HEADER

```
UFUNCTION(Server, Reliable, WithValidation,
BlueprintCallable)

  void Server_myFunction();

void Server_myFunction_Implementation();

bool Server_myFunction_Validate();
```

Reliably calls Server_myFunction(). Can be called from any owning client but will only perform the function on the server. Can be called from Blueprints.

NETWORKING FUNCTION EXAMPLE: CPP

```
void AMyActor::Server_myFunction_Implementation()
{
  //Execute what the server should do here
}

bool AMyActor::Server_myFunction_Validate()
{
  //Perform necessary validation of function here
  return true;
}
```

Only implement the _Implementation() thunk. **Must** include _Validate() to work.

NETWORKING FUNCTION EXAMPLE: HEADER

```
UFUNCTION(Unreliable, Netmulticast)
  void Netmulticast_myFunction();
void Netmulticast_myFunction_Implementation();
```

Unreliably calls Netmulticast_myFunction(). If called from the server, will execute on all clients.

NETWORKING FUNCTION EXAMPLE: CPP

```
void
AMyActor::Netmulticast_myFunction_Implementation()

{
  //Execute what the server and all clients should
do here

}
```

Only implement the _Implementation() thunk.

WHAT TO REPLICATE?

- Very challenging software architecture question!
- For any project that may require networking, you want to *build networking in as soon as possible*
- Must choose what will be controlled on the server versus the clients
- Common things the server replicates:
  - The world itself
  - Interactables in the world
  - Playable characters
- Common things to run locally:
  - GUI and HUD
  - Certain animations
  - Anything only relevant to the owning player

WHEN TO REPLICATE RELIABLY?

- Replicate as unreliably as possible
  - State-related changes should always be replicated reliably
  - Anything cosmetic or frequently sent can be replicated unreliably
- Only replicate what is important to the clients
  - Do not replicate world or player information that will not effect the client

RPCS AND OWNERSHIP

- Ownership determines how and where these functions are called
  - If Actor is owned by server, RPC is called on server
  - If Actor is owned by a client, RPC needs to know which client
- PlayerController can be an **owning connection** of an Actor (e.g. a Pawn)
  - When Pawn is possessed by PlayerController, it is owned by that PlayerController's connection
  - No longer owned by PlayerController's connection when unpossessed

ROLE AND REMOTE ROLE

- Actors have a Role and a RemoteRole property
- Roles are: `ROLE_Authority`, `ROLE_SimulatedProxy` and `ROLE_AutonomousProxy`
  - Simulated Proxy used for Actors controlled by server (client updates values accordingly)
  - Autonomous Proxy used for Actors controlled by a player (client considers values from input in addition to values passed down by server)
- Note: Roles will change depending on who is inspecting the values
- Example: Actor is owned by server and simulation is passed to clients
  - On server, sees `Role == ROLE_Authority` and `RemoteRole == ROLE_SimulatedProxy`
  - On client, sees `Role == ROLE_SimulatedProxy` and `RemoteRole == ROLE_Authority`

UE5 REPLICATION GRAPHS

- Designed to handle the large number of players and Actors in Fortnite without taxing CPU as heavily or having a laggy experience due to less frequent updates
- Replication Graph contains nodes with information on how/when to send data to clients about Actors
  - Do clients ever need to receive updates on this Actor?
  - When will specific clients need to receive updates on this Actor and how frequently?
- Graph system designed to be flexible to suit the needs of the project
  - Consider when and how replication occurs and create data structure accordingly

THINK ABOUT THE REPLICATION CONSIDERATIONS IN THE SCENE BELOW...