Remote Visualization With ParaView

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Overview

Part 1 - Getting connected

- ParaView client/server architecture
- Running and connecting the client and server
- Connection types
- Connecting to remote clusters

Part 2 - Remote visualization

- What happens where
- Remote vs. local rendering
- Speeding up remote rendering

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Part 1
Getting connected

ParaView Architecture

ParaView client - application with user interface

- Runs on the desktop to visualize local data

ParaView server (pvserver) - server application

- Runs on remote system
- Can be built with MPI for parallel visualization on clusters

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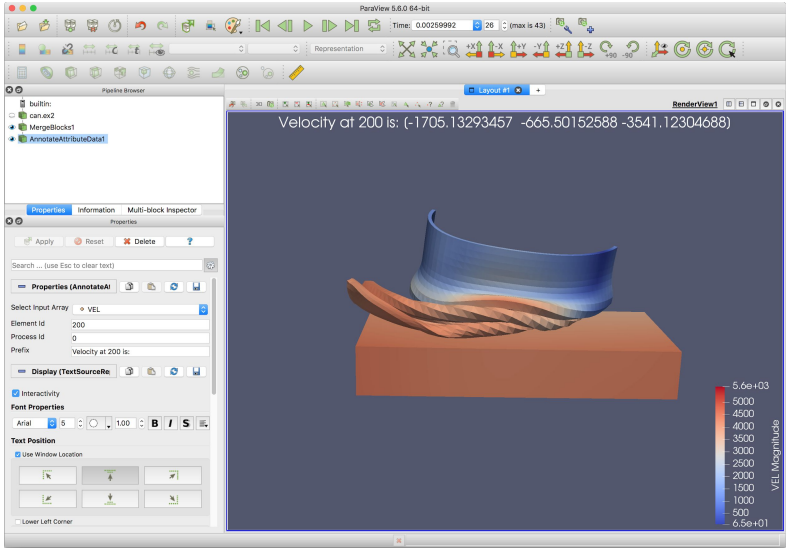
ParaView client application

Is a GUI application

Scriptable with Python

Connects to a server for visualization

By default, is connected to a built-in server in the same process, offering standalone visualization capabilities.



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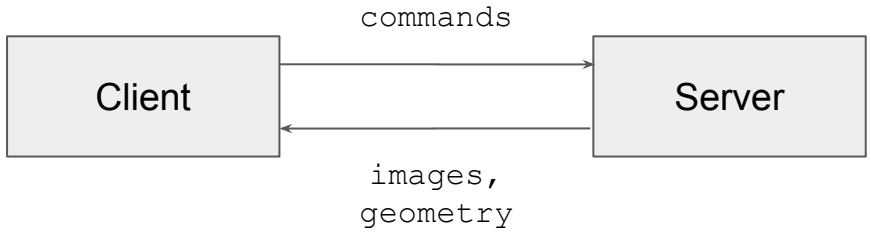
ParaView server

Executable named `pvserver` that runs on a remote system where data resides

- No GUI available (do not forward X11 to your client workstation)
- Connects to a client that drives the visualization session



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ParaView server - graphics requirements

Can use graphics acceleration if available

- Can use X11 to access graphics accelerators
- If NVIDIA nodes are available, building with EGL is possible (no X11 required)
- If neither X11 nor EGL are available, can do software rendering with offscreen Mesa OpenGL library

When running `pvserver` remotely through SSH, do not enable X11 forwarding with `-x` or `-y`

- This could cause rendering to happen on the client!

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ParaView server - MPI

`pvserver` can be built with or without MPI (with is recommended)

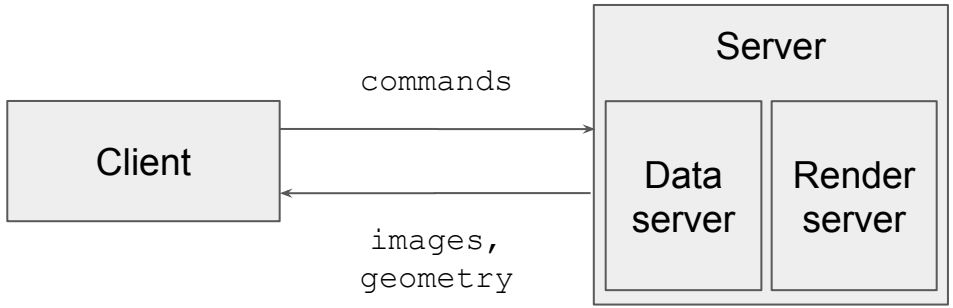
- In both cases, connecting the client to the server is the same
- Client connects to rank 0 on the server, process 0 coordinates ranks

Application binaries provided by Kitware are built with MPICH 3.2

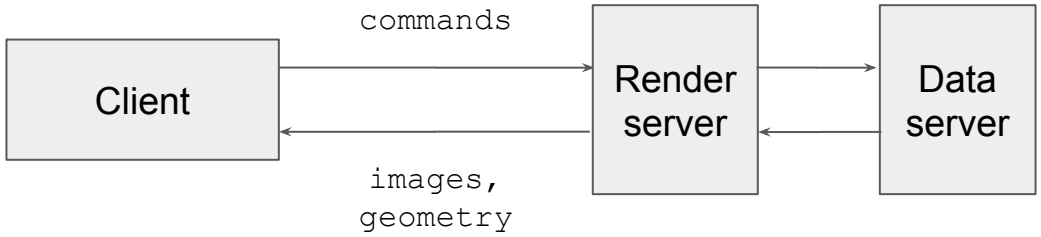
- This is probably not optimal on your system
- If system has hi-speed interconnect, you will want to build `pvserver` with MPI for the interconnect

Side note - data server, render server

`pvserver` is actually two servers, a data server and a render server



The two servers can be run separately, but not often used this way



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Running pvserver

Run `pvserver[.exe]` at a terminal

Linux -

`pvserver` is in same bin/ directory as paraview

macOS -

`pvserver` is in /Applications/ParaView-5.6.0.app/Contents/bin

Windows -

`pvserver.exe` is in C:\Program Files\ParaView-5.6.0*\bin

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`pvserver` waiting for a connection

```
> pvserver
Waiting for client…
Connection URL: cs://terminus.local:11111
Accepting connection(s): terminus.local:11111
```

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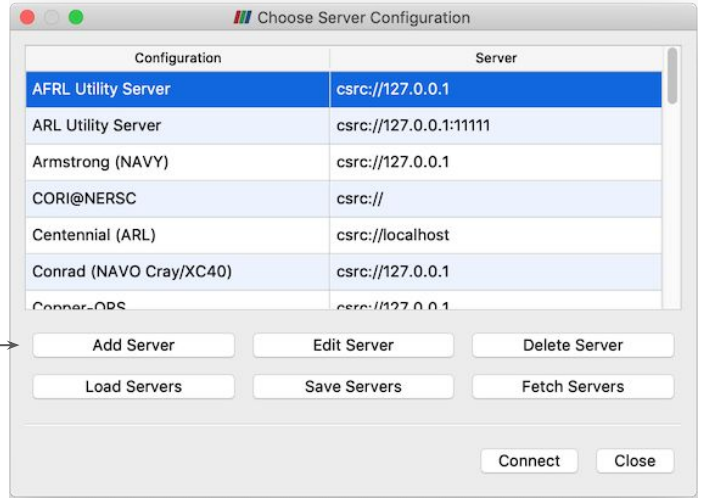
Connecting the client

In client, clicking the  button brings up connection dialog.



Click here to add a new server

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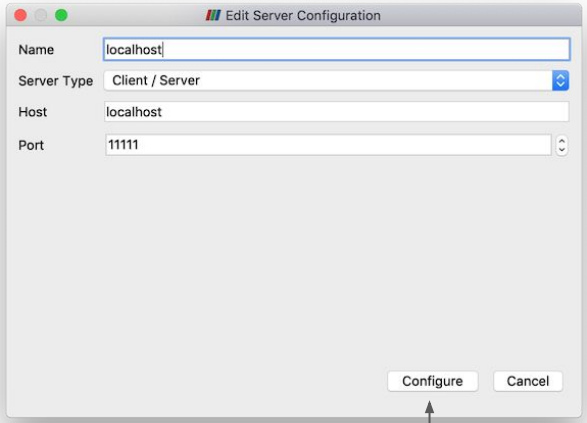
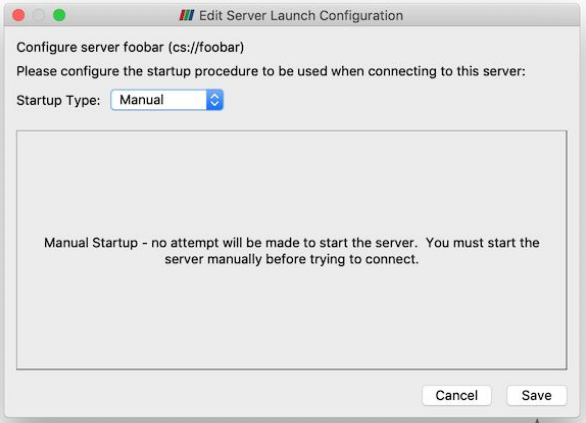
Add forward connection to localhost

Add a configuration to connect to a server running on same machine as client



Enter text, click **Configure**



Click **Save**

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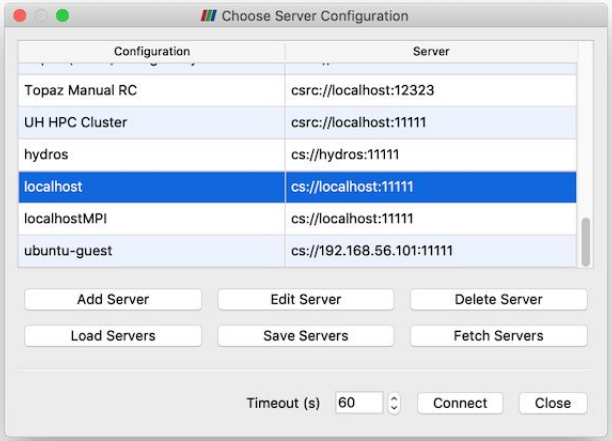
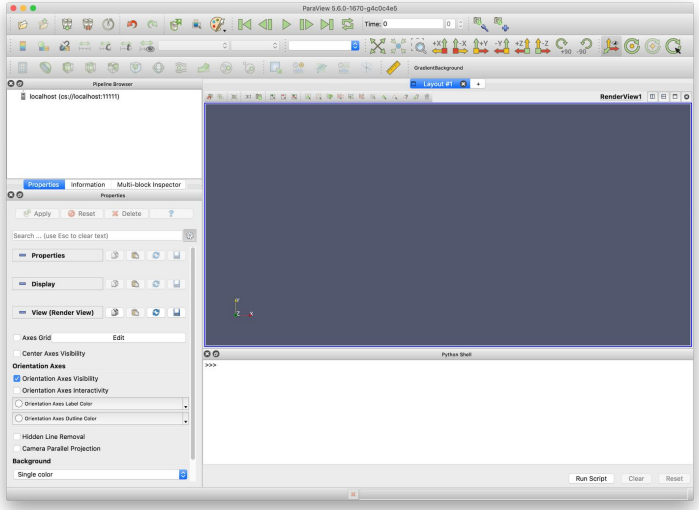
Connect to localhost

Select localhost configuration and click **Connect**



Connected server shown here



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Try it

Navigate to your ParaView installation

Run `pvserver` on your local system with no arguments

Set up a new connection configuration 

Connect to the server from the ParaView client

Disconnect by clicking 

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Running `pvserver` in parallel

You can run `pvserver` like any other MPI program

```
> mpiexec -np <num processes> pvserver [additional arguments]
```

*Windows version built with MPI requires MS-MPI (free download) to be installed

Connecting to the server is the same as when it is run serially

Running `pvserver` in a job queue

Typically need to submit batch job

```
qsub -A <project to charge time to>
  -N <number of nodes>
  -n <number of cores on each node>
  -q <job to submit job to>
  mpiexec -np <N*n> pvserver
```

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Forward connections

> `pvserver`

Listens for incoming client connection on port 11111

> `pvserver --server-port=22222`

Listens for incoming client connection on custom port 22222

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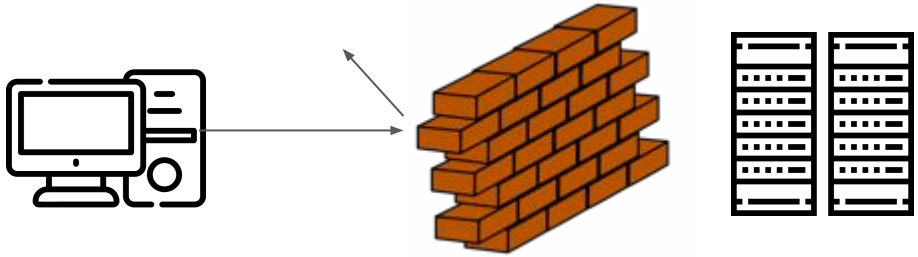
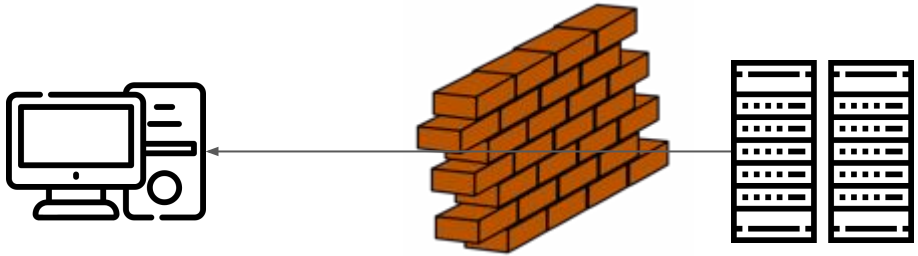
If only it were that simple...

No HPC cluster is open to the internet with an open socket connection



Common solution - have the server connect to the client



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Reverse connections

ParaView client listens for incoming connection, `pvserver` initiates connection to `--client-host` argument

```
> pvserver --reverse-connect --client-host=localhost
```

This is a new type of connection, so we need to add a new connection configuration to the ParaView client

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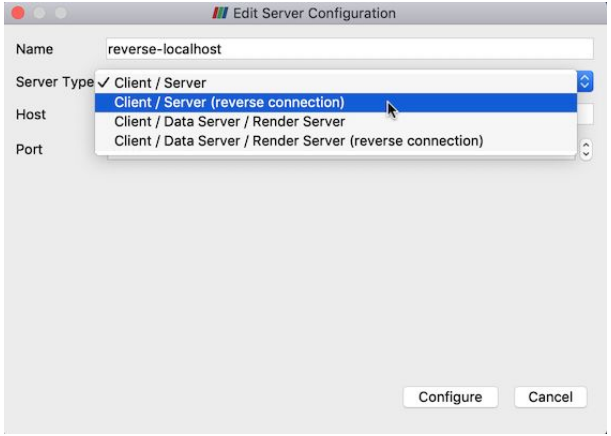
Configure reverse connection

Add a server in the **Choose Configuration Server** dialog

Set **Server Type** to “Client / Server (reverse connection)

Click **Configure** and click **Save** on the next screen



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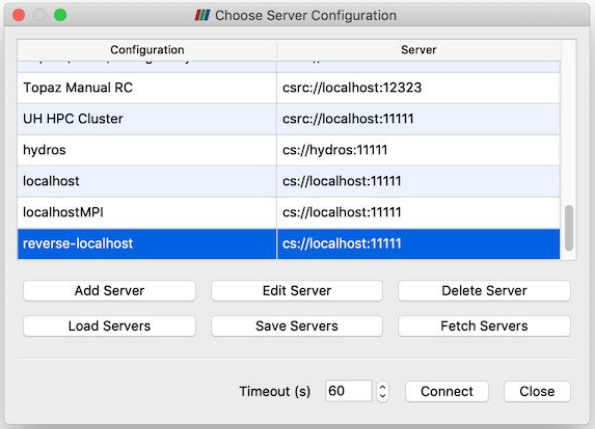
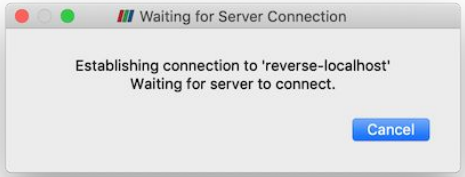
Connect the server to the client

Run `pvserver --reverse-connect --client-host=localhost`

Select the **reverse-localhost** configuration and click **Connect**





Server will output:

```
Connecting to client (reverse
connection requested)...
Connection URL: csrc://localhost:11111
Client connected.
```

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Try it

Set up a new connection configuration 

Name: reverse-localhost

Host: localhost

Port: default (11111)

Server Type: “Client / Server (Reverse Connection)”

Connect in the **Choose Server Configuration** dialog

```
> pvserver --reverse-connection --client-host=localhost
```

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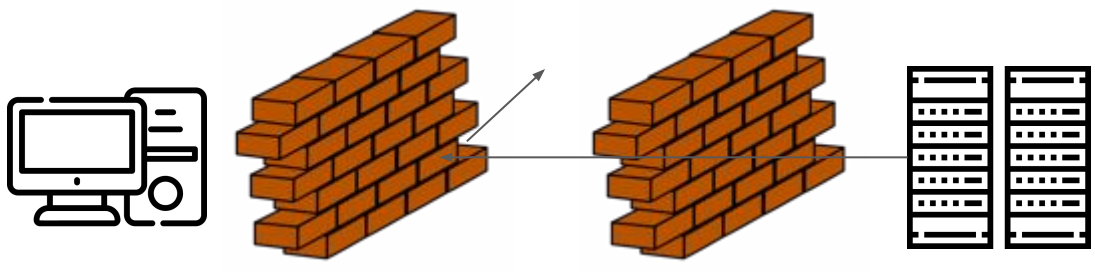
If client is behind a firewall...



A reverse connection alone will not work in this scenario

Outside connections cannot get to ParaView client behind firewall

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SSH tunneling

Usually systems behind firewalls can be accessed via SSH

SSH allows a mechanism called “tunneling” that can be used to bypass firewall restrictions on network connections in a secure way by sharing the SSH connection with other network connections

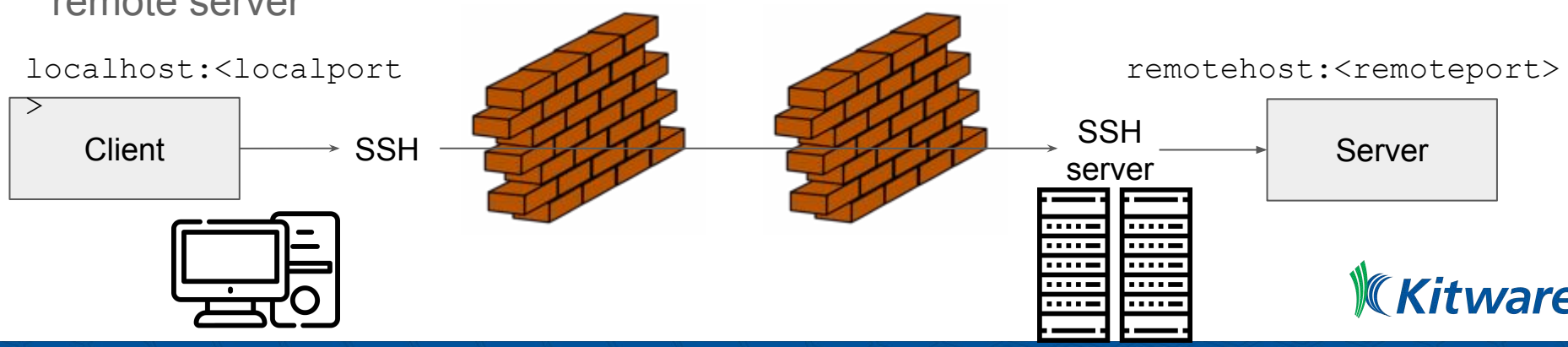
We can use this to create secure ParaView client/server connections through firewalls

SSH forward tunneling

```
> ssh -L <localport>:<remotehost>:<remoteport> <server>
```

SSH will listen on <localport> for a connection and forward the connection to <remotehost> on port <remoteport>

ParaView client connects to localhost:<localport> and SSH forwards this to the remote server



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SSH forward tunneling

Server side

```
localhost> ssh -L <localport>:remote:<remoteport> user@remote

remote> pvserver --server-port=<remoteport>
```

Client side

Add a new “Client / Server” (forward) connection where server **Host** is “localhost” and **Port** is <localport>

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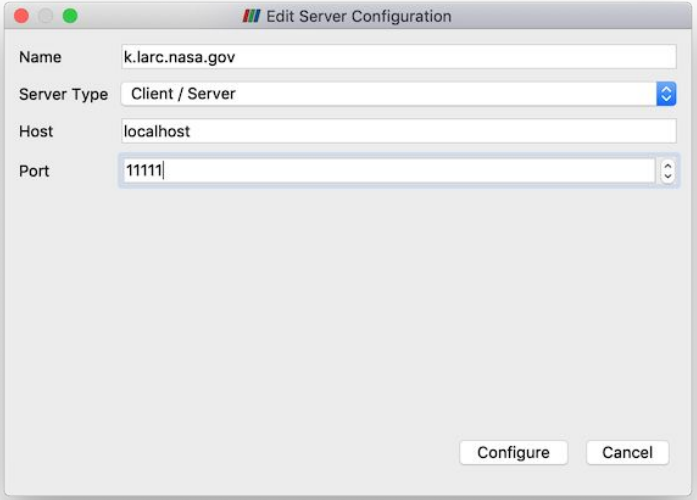
SSH forward tunneling - concrete example

Server side

```
localhost> ssh -L
11111:k.larc.nasa.gov:22222
user@k.larc.nasa.gov

user@k > pvserver \
  --server-port=22222
```

Client side



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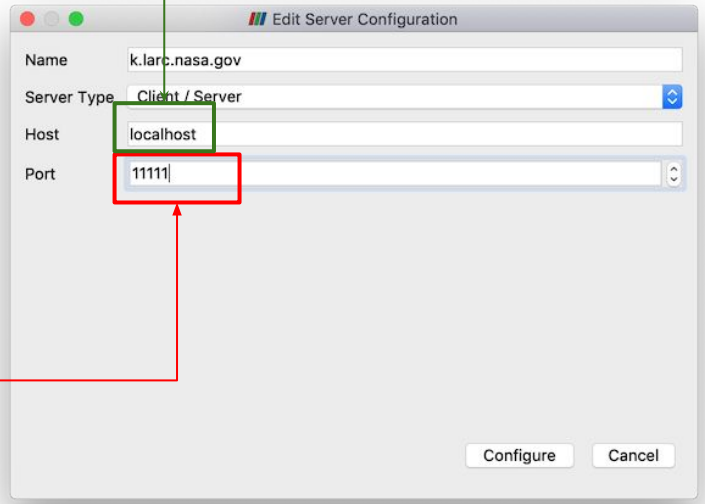
SSH forward tunneling - concrete example

Server side

Client side

```
localhost> ssh -L
11111:k.larc.nasa.gov:22222
user@k.larc.nasa.gov

user@k > pvserver \
  --server-port=22222
```



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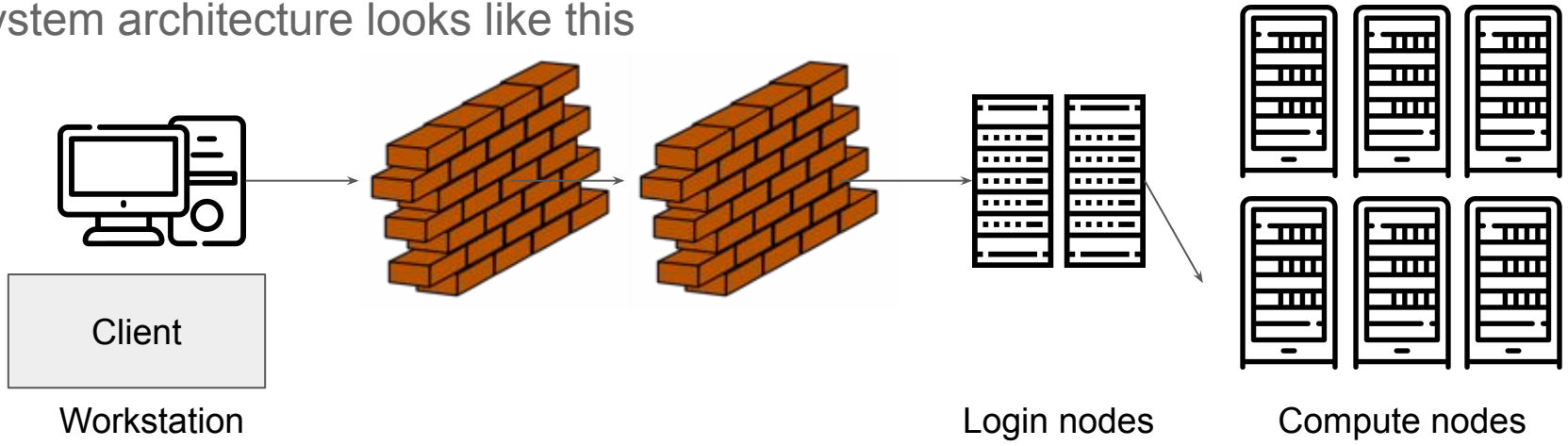
Those pesky login nodes

Typically, there are dedicated login nodes separate from compute nodes

System architecture looks like this



How do we tunnel to a compute node?

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SSH forward tunneling with login nodes

Login nodes are not used for compute

- You need to submit a job to a queue
- You won’t know the DNS of the compute node

Forward tunneling relies on you knowing the hostname of the compute node

- How do we get that?

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SSH forward tunneling to compute node

Solution: use two terminals

Terminal 1: SSH into login node, queue job, get hostname of compute node

```
t1> ssh user@k.larc.nasa.gov
t1> qsub -I -l nodes=1 -q K4-standard
t1> hostname
compute-node21
```

Terminal 2: SSH into login node, set up forwarding from client to compute node

```
t2> ssh -L ZZZZZ:compute-node21:YYYYY user@k.larc.nasa.gov
```

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SSH forward tunneling to compute node

Launch `pvserver` on Terminal 1

```
t1> mpiexec -np <N> pvserver --server-port=YYYYY
```

With the ParaView client, connect to localhost on port `ZZZZZ`

This should connect the ParaView client through the SSH tunnel set up in Terminal 2 to the server on the compute node

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Two terminals is too many

Forward tunneling with two shells is cumbersome!

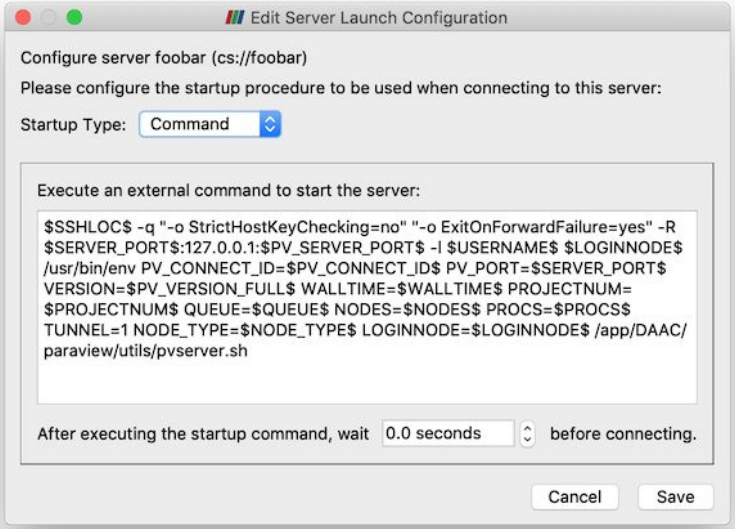
We can take care of launch of `pvserver` and connecting with a reverse SSH tunnel

Key is to use a Command **Startup Type** that starts `pvserver` when connection is made

Note variables such as $USERNAME$

These are defined in a .pvsc definition file that you can import to define server connections

Example:



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Example XML for previous connection

```
<Server name="Topaz (ERDC)" resource="csrc://localhost:11111">
    <CommandStartup>
      <Options>
        <Option name="USERNAME" label="Username" save="true">
          <String default=""/>
        </Option>
      </Options>
        …
      <Command exec="$SSHLOC$" timeout="0" delay="0">
        <Arguments>
          <Argument value="-q"/>
          <Argument value="-R"/>
          <Argument value="$SERVER_PORT$:127.0.0.1:$PV_SERVER_PORT$"/>
          <Argument value="-l"/>
          <Argument value="$USERNAME$"/>
        …
```

ParaView can download .pvsc file from URL and add connection configurations automatically

Configured servers are stored in .pvsc file in home directory:

%APPDATA%/ParaView/servers.pvsc
~/.config/ParaView/servers.pvsc

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Reverse connection

Connect button launches a program to SSH into and authenticate with login node and launches a script there. Client then waits for reverse connection from `pvserver` running on compute node. No separate SSH connection required.

The script:

Finds out login node's IP address

Submits a `pvserver` job through queue

`pvserver` job starts with `--reverse-connection` back to the waiting GUI client over the tunnel

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Reverse connection caveats

When login and compute nodes are separate, SSH daemon needs to have *AllowTCPForwarding* and *GatewayPorts* enabled

If not enabled, reverse connection cannot be made back to the client

Workaround is to use port forwarding utility such as `socat` on the login node listen for a connection on the compute node and forward it back to the client

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Reverse connection wrap-up

Offers a path to one-click connection to a remote cluster

May require assistance of a system administrator to set up, but then it is easy to make it available to all users

- Pass around a .pvsc file with configuration
- Download from a URL, for example: File->Connect->Fetch Servers

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Part 2
Remote visualization

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Loading data

Once a client and server are connected, we are ready to load data and visualize it

To open a data file, select the **File** -> **Open…** menu item

The file dialog shows files on the file system available to `pvserver`

You cannot load data on the local file system as long as the connection is alive

- Disconnect first to connect to the builtin server and load local data

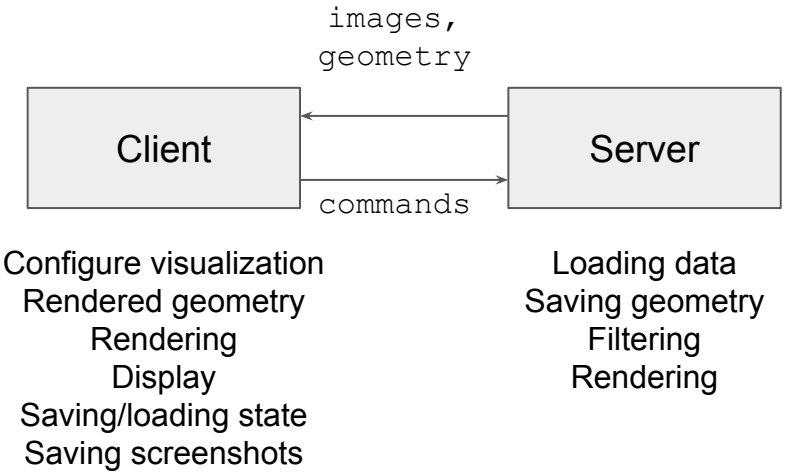
What happens where?

Data is loaded onto the `pvserver` processes

Filtering is performed on `pvserver`

Subsets of data can be sent to the client for local rendering

Rendering *can* be performed on `pvserver`, but it can also be done only on the client



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Where should rendering happen?

Client

Pros:

- Low latency from render request to render
- High frame rate

Cons:

- Fewer resources on client machine
- Network transfer time for geometry

Server

Pros:

- No geometry to transfer to client
- Can handle larger datasets

Cons:

- Higher latency, lower frame rate
- One image sent over network per render

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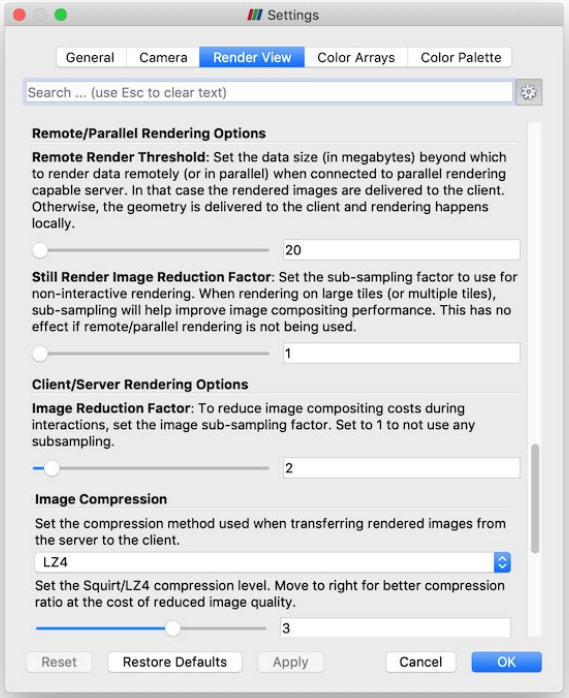
Controlling where rendering happens

Usually, geometry is extracted from a dataset to be rendered

Remote Render Threshold determines where rendering happens

Available under **Edit** -> **Settings/ParaView** -> **Preferences**



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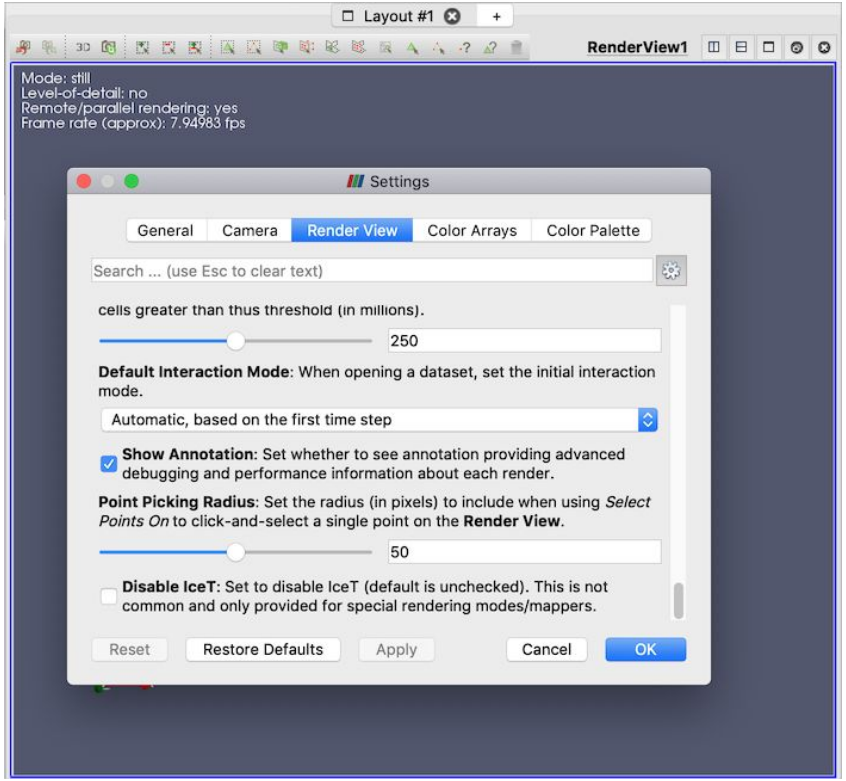
Verifying where rendering occurs



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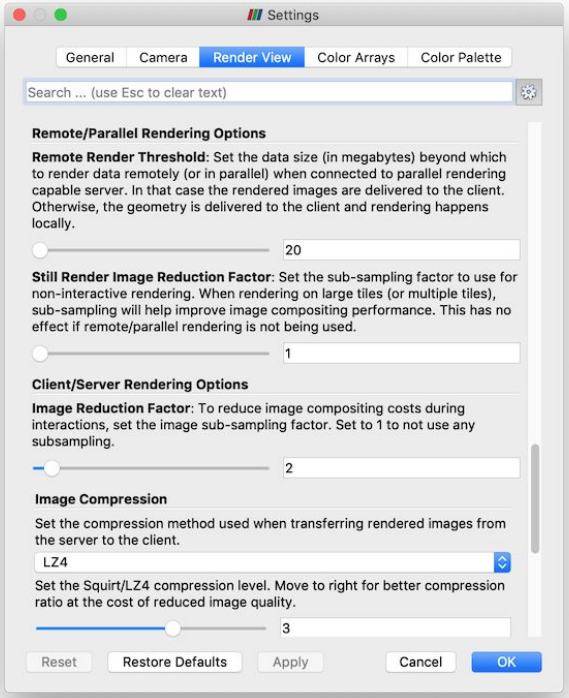
Speeding up remote rendering - low bandwidth

Still Render Image Reduction Factor - subsample images when full quality rendering is requested

Image Reduction Factor - subsample images generated during interactive rendering

Image Compression - compression algorithm and amount of compression to use



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Speeding up remote rendering - high latency

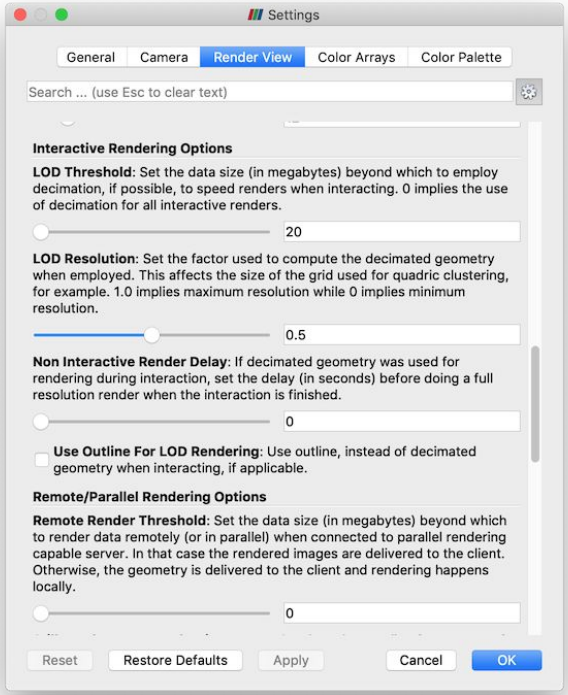
Play with the **LOD Threshold** and **LOD Resolution** to reduce geometry sent to client.

Turn on **Use Outline for LOD Rendering** if decimated geometry too big for client.

Try increasing **Non Interactive Render Delay**

Turn up **Remote Render Threshold**

Allow more data to go to client



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Remote visualization with Python

`pvpython` is a ParaView client application that can generate images from a Python script

To connect to a pvserver on a remote system, use the Connect() function

```
>>> Connect("server.host", 11111)
```

Once connection is established, Python commands can be run to create filters and generate images on the server

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Questions?

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