HPC Enabled Real-Time Remote Processing of Laparoscopic Surgery

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Introduction

- Laparoscopic surgery reduces patient trauma, hospitalization stay and recovery time
  - Small field of view of the laparoscope and small incision size results in a small overall visual field
  - Image-guided surgical (IGS) techniques use pre-operative and intra-operative images to map a surgical region of interest, providing surgeons with visualization of subsurface structures
  - The accurate co-registration of IGS system with laparoscopic video reduces limited surgical access and allow for a resection with higher specificity and tighter margins, sparing more healthy tissues
- The daVinci-Si robot has stereoscopic parallel 1080p (1920x1080x3) High Definition (HD) video cameras for vision, producing 30 frames per second (fps)
  - The HD video streams generate approximately 360 megabytes per second (MB/s) of video data
- To process this data on remote HPC clusters at 30 fps rate, requires each 11.9 MB video frame be processed, returned and displayed within 1/30th of a second

da Vinci cardiac surgery

da Vinci robotic surgical system

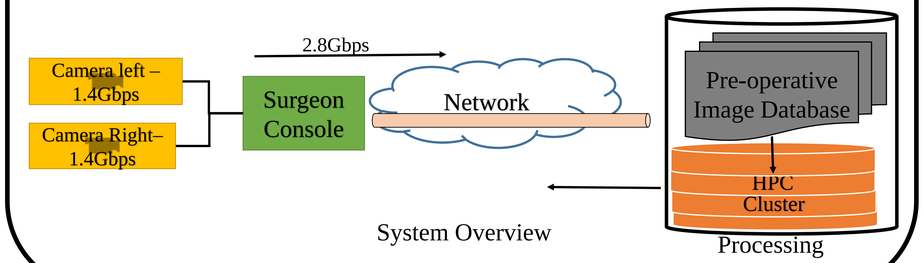
Challenges

Networking Challenges

- **Latency**
- **Bandwidth Sharing**
- **Packet Contention**
- **Reliability**
- **Security**

Compute Challenges

- **High Definition Video Processing**
- **Stereoscopic Camera Processing**
- **Multi-Dimensional Pre-operation data overlay eg CT, MRI, Ultrasound, etc.**
- **Multi-Algorithmic Operations**
  - **Transformation**
  - **Registration**
  - **Compression/Decompression**

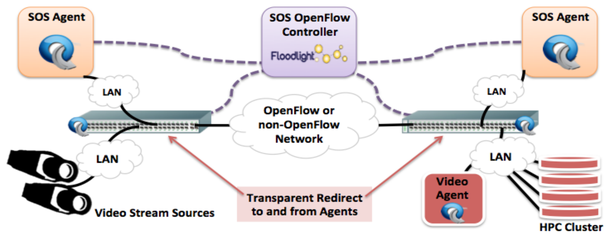


System Overview

Processing Location

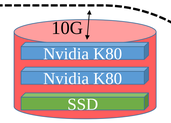
Framework

Networking Solution



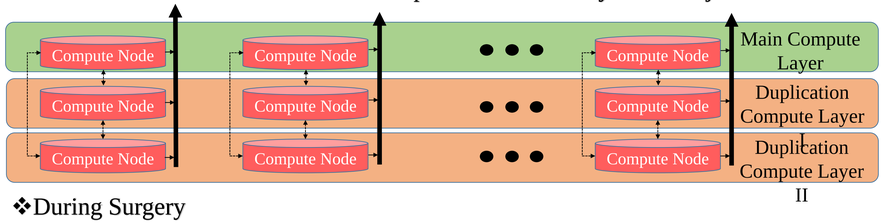
- TCP is reliable, but can jeopardize timely data delivery upon packet loss
  - Occasional packet loss reduces window size → less throughput
  - This can impact real-time applications, which must either slow the rate of transfer, or in the case of video streaming, reduce the quality of the video
- Network performance can be enhanced through Steroid OpenFlow Service (SOS)
  - OpenFlow solution provides a network service to transparently parallelize TCP connections via in-network SOS "agents"
  - Increases throughput by filling more of the pipe over large delay-bandwidth-product networks
  - Removes single point-of-failure; data spread across multiple TCP connections; packet loss on a single connection does not impact others
  - Multipath support eliminates link single point-of-failure and increases parallelism spreading parallel TCP connections across multiple links
- Supplemental OpenFlow agent in HPC cluster
  - TCP-to-UDP video stream conversion and replication to HPC servers

Compute Solution



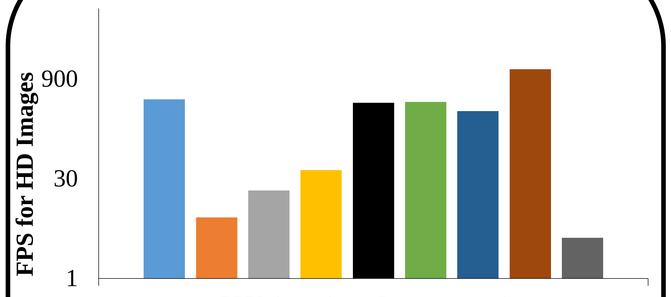
Compute Node Structure

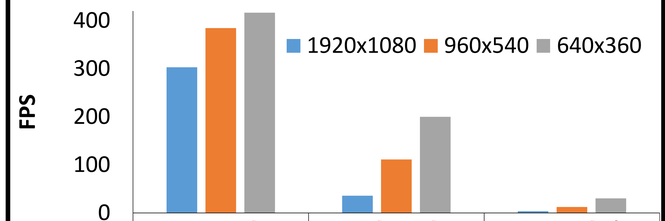
- Pre-surgery Setup
  - Transfer pre-operative image database to all compute nodes
  - Transfer images and database to GPU Memory
  - Allow for warm-up for network protocol by transferring images
  - Perform verification of compute nodes in all layers in the job



- During Surgery
  - Enable image overlay are sent back to Surgeon Console →Flexibility
  - Add compute node in case of failure/addition of Algorithms→Scalability
  - Duplication Layer allows for verification of data → Reliability
  - Allow verification at every 10th frame thus allowing at max
    - Using GPU-Direct and CRC for verification of output
  - Change Main Compute Layer incase of failure

Preliminarily Results





	Canny Edge detection	Bilateral filtering	Mean shift segmentation
1920x1080	303.030303	35.71428571	3.571428571
960x540	384.6153846	111.1111111	12.34567901
640x360	416.6666667	200	30.3030303

Conclusion

- In computer assisted-surgery, particularly image-guided surgery the ability to acquire, process, and visualize data in real-time is essential for performance of complex tasks, minimizing risk to the patient
- Through the use of high-speed access to hpc resources, it will be possible to update models and allow for real-time modification of surgical data
- We will also ensure security, reliability and scalability of data during surgical procedures

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