UltraGrid: Low-Latency High-Quality Media Transmissions on Commodity Hardware

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Overview

Introduction

UltraGrid Features

UltraGrid Community

What’s New?

About the Demo

Current & Future Development
Concert from HAMU, Prague

Ondřej Kabrňa

http://www.ondrejkabrna.com/


Jazz Piano Standards
What is UltraGrid?

- Affordable platform for high-quality interactive video transmissions using commodity hardware
  - high-resolution video: HD, 4K, 8K
  - as low latency as possible on commodity hardware
  - commodity equipment
    - Linux, Mac, Windows
    - common GPUs and video capture cards
  - open-source software, dual BSD/GPL license
    - UltraGrid itself is BSD-licensed, may become “GPL infected” (e.g., x264)
  - picks up where common videoconferencing ends
    - 10 Mbps – 10 Gbps (or more)
Who Is UltraGrid For?

- “Power users”
  - scientific visualizations
  - medicine: X-ray imagery, cardiology, surgery, emergency medicine training support, pathology, …
  - education: remote lecturing
  - arts, cinematography, broadcasting
  - collaborative environments: multi-point operation
  - many others
Who Is UltraGrid For?

- Researchers
  - experimental validation of your research results
  - Holub et al.: real-time image processing algorithms
  - Perkins et al.: network protocols, congestion control,…
  - Holub & Rudová et al.: data distribution models & scheduling
  - Renambot et al.: image compression & large scale visualization systems
  - Hutana et al.: distributed visualization systems
Bandwidth – Latency – Commoditization

- CESNET MVTP-4K
  - custom hardware
  - <1 ms latency SDI → IP → SDI: uncompressed, local network
  - 1–10 Gbps, depending on video format

- LoLa
  - specialized hardware for PC hardware
  - 2 ms audio latency, 10 ms video latency
  - 100–1000 Mbps, depending on video format
  - (Claudio, feel free to correct :)

- UltraGrid
  - commodity hardware
  - <10 ms audio latency, 70–150 ms video latency depending on hardware and compression
  - 10 Mbps–10 Gbps, depending on video format, compression, etc.
UltraGrid for Medicine

...on special request

- Cardiosurgery
  - detailed view from the HD cameras

- Angiology
  - real-time composition of various modalities on 4K screens: X-ray, FFR, OCT
  - image anonymization is a must
UltraGrid for Medicine
...on special request
History of UltraGrid

- History of Development
  - 2005–2012: CESNET (→ 1080i)
  - 2006–2008: forks by KISTI (GUI, AJA KONA) and i2cat (SAGE)
  - 2013: i2cat starts contributes to common codebase maintained by CESNET

- Some milestones
  - 2002: 720p
  - 2005: 1080i, multipoint
  - 2007: CPU compressions, self-organization, optical multicast
  - 2008: 2K/4K
  - 2011: GPU compressions
  - 2012: 8K
World Firsts…

- 2005 – Multi-Point Uncompressed HD

- iGrid 2005 – two independent n-way demos
  - UltraGrid: using packet reflectors
  - iHDTV: multicast
World Firsts…

- 2007 – Self-Organizing Multi-Point Uncompressed/Compressed HD
  - with CoUniverse
  - self-organizing multi-point distribution setup with uncompressed/DXT1 compression switching based on available bandwidth
World Firsts…

- 2012 – GPU-JPEG Transatlantic Multi-Point 8K
  - from pre-rendered sources
  - JPEG → DXT5-YCoCg on a single machine
  - useful also as 16× HD (multi-camera setups)
Features of UltraGrid

- Supported video formats
  - HD, 2K
  - 4K – tiled or native
  - 8K – experimental, problems with available sources
  - (almost) arbitrary video resolution
  - multichannel video (e.g., 3D HD, 4K)

- Uncompressed vs. compressed
  - only interested in low-latency compression
  - GLSL-accelerated DXT1, DXT5-YCoCg
  - CUDA-accelerated JPEG, DXT5-YCoCg
  - CPU-based low-latency H.264 via x264 & libavcodec
    - that’s when UltraGrid becomes GPL
Features of UltraGrid

- Video input
  - capture cards: HD/3G/6G-SDI, SDI, HDMI (incl. stereoscopic HDMI 1.4a), analog HD and SD
    - vendor SDKs: Blackmagic, DeltaCast, BlueFish444
    - vendor-independent: Video4Linux2, QuickTime, DirectShow
  - screen capture input
    - beware of cursor – may be lost, depending on the API
  - testcard
  - file input
- Video output
  - playback cards: HD/3G/6G-SDI, SDI, HDMI (incl. stereoscopic HDMI 1.4a), analog HD and SD
    - best for displaying interlaced video
  - computer screen output (OpenGL, SDL)
  - SAGE output
  - file output
  - specialized display filters
Features of UltraGrid

- Video processing
  - deinterlacer
  - software video mixer with overlay support
    - probably the only affordable real-time mixer with scaling support for 4K right now
  - logo overlay
Features of UltraGrid

- **Audio**
  - balanced, unbalanced
  - standalone (sound card) or embedded (in HD-SDI, HDMI)
  - various system interfaces including JACK
- **Supported audio formats**
  - various sample rates, multi-channel
- **Uncompressed vs. compressed**
  - uncompressed by default
  - OPUS codec compression available
- **Synchronization of audio with video**
  - depends on the source, if it is synchronized
  - synchronized when using HD-SDI and HDMI as audio source
  - audio is transmitted with as low latency as possible when using standalone soundcard
Features of UltraGrid

- Network transmission format – extended RTP
  - IP/UDP/RTP is used as the basic format
    - backward compatible with RTP tools, e.g., for monitoring
  - extended application headers for additional flexibility
    - extended packet numbering
    - flexible specification of media parameters, format, compression, etc.
    - notion of “buffer position” – does not depend on uncompressed structure as RFC 4175
Range of Applicability

Bandwidth

- HD (1080p @ 30p)
  - H.264: 10–50 Mbps
  - M-JPEG: 50–200 Mbps
  - uncompressed: 1–2.2 Gbps
- 4K (2160p @ 30p)
  - H.264: 30–100 Mbps
  - M-JPEG: 150–600 Mbps
  - uncompressed: 4–9 Gbps
- 8K (4320p)
  - M-JPEG: 500 Mbps–2 Gbps
  - (uncompressed: >10 Gbps)
- 1–3× for Forward Error Correction (FEC)
Range of Applicability

Lantecy

- End-to-end latency (capture to playback) in local network
  - <150 ms for interactivity: ITU-T rec G.114
- Video
  - depends on capture/playback hardware: 1.75–5.5 frames (58–183 ms)
  - e.g., ≈ 2 frames: BlackMagic Decklink HD Extreme → OpenGL on MacOS x
- Audio
  - video embedded: synchronous
  - independent source/playback: 20 ms or less
Video Compression

- GPU-accelerated compression schemes
  - JPEG: NVidia CUDA based (http://gpujpeg.sf.net/)
  - DXT1, DXT5: OpenGL Shader Language (GLSL) based
  - DXT5: NVidia CUDA based (for 8K)
- CPU compression
  - H.264
  - DXT1: CPU-based (FastDXT library from EVL)

SAGE display with various compressions
Video Compression

- Performance numbers (including transfer to/from GPU)
  - DXT1 GLSL: 798 Mpix/s (NVidia 580GTX), 593 Mpix/s (ATI 6990)
  - DXT5 GLSL: 349 Mpix/s (NVidia 580GTX), 305 Mpix/s (ATI 6990)
  - JPEG CUDA: up to 1.580 Mpix/s = 4.740 MB/s (NVidia 580GTX, 4:4:4, Q=60)
  - DXT5 CUDA: ≥1.580 Mpix/s (NVidia 580GTX)

(c) Encoder performance (both CPU and GPU)  
(d) Decoder performance (both CPU and GPU)
CPU-Based H.264

- X264 library provides low-latency H.264 mode
  - no B-frames are used
  - distributed I-frames to avoid bandwidth spikes
- Practical usability
  - HD @ 30p: 4 core Core i7 system
  - 4K @ 30p: 12 core Intel Xeon system
- X264 library is GPL or commercially licensed
  - UltraGrid becomes GPL when linked with it
  - commercial license can be obtained for commercial projects
Latency Impact of Compression

- Uncompressed for DeckLink HD → DeltaCast 3G
  - 2.5 frames (83 ms)
- Impact of compressions
  - 2.5 frames (+<16.7 ms) for CUDA JPEG
  - 3.5 frames (+33.3 ms) for GLSL DXT1/5
  - \( \approx \) 5 frames (+83.3 ms) for H.264
Quality Impact of Compression

- **ABX testing of M-JPEG**
  - test of distinguishability of uncompressed vs. compressed video
  - GPU JPEG (with precise DCT transforms – no color casts)
  - setup in native environment for give application

- **Angiology:**
  - \( Q \geq 90 \) undistinguishable

- **Cinematography screening:**
  - \( Q \geq 80 \) undistinguishable
  - \( Q \in [60; 80) \) distinguishability substantially varied among viewers

More details in:
Forward Error Correction (FEC)

- LDGM
  - CPU and GPU implementations
  - CPU (SSE optimized) is used because of CPU ↔ GPU transmissions overhead
  - packet loss up to 10% can be mitigated with reasonable overhead
  - can make JPEG survive up to 25% packet loss

- Simple method: shifted multiplication
  - used for audio by default
User-Empowered Multi-Point Distribution

- UltraGrid supports multicast, but...
  - how available/dependable it is?
- UDP packet reflectors
  - controlled by the user
  - lower efficiency
  - possible per-user processing: transcoding, security,…
- Transcoding reflectors
  - per user processing, individual quality adjustments
- Self-organization of the network
  - research problem: scheduling streams with bitrates comparable to capacity of links
  - CoUniverse framework (http://couniverse.sitola.cz)
Users Worldwide

- Distribution:
  - source, binaries (http://www.ultragrid.cz/, SourceForge)
  - embedded in SAGE (http://www.sagecommons.org/)

- Installations around the world:
  - Czech Republic (universities and university hospitals), USA (UCSD, UMich, UIC, Internet2, NLM/NIH, NorthwesternU, ...), Spain (i2cat, UPM), Portugal (FCCN), Netherlands (SARA), Poland (PSNC), Korea (KISTI), Russia, Germany (H-BRS), Japan (AIST),...
Open-Source Development Model

- Why?
  - because it allows to implement your research

- Contributors
  - current: CESNET, Masaryk University, i2cat, EVL UIC
  - past: ISI EAST, CCT LSU, SARA

- Benevolent dictators for life
  - we review before accepting/committing
  - to maintain and improve code quality
  - we welcome your contributions!
What’s New? – Release 1.2

- MS Windows support
- New hardware support
  - capture cards: DELTACAST, BlueFish444
- File-based I/O
- Transcoding reflector
- Integration of 2-camera GColl
  - group-to-group communication with partial gaze awareness
  - experimental
- Software video mixer
  - up to 4K video in real-time
- Image anonymization (for medical apps)
- Current software echo canceller deprecated
  - problem with frequency drift of common sound cards
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Demo Scheme

HAMU, Prague
Running the Demo

- **UltraGrid setup @ HAMU in Prague:**
  ```
  uv -t decklink:1:24 -s embedded -d decklink:0 -r analog \\ 
  -c JPEG:80 --audio-capture-channels 2 -l 500M \\ 
  -f ldgm:1000:500 codec3.nws.edu
  ```

- **UltraGrid setup @ NWS in Miami:**
  ```
  uv -t v4l2:/dev/video0:MJPG:1920:1080:1/30 \\ 
  -s alsa:sysdefault:card=MTrak -r alsa:sysdefault \\ 
  -d gl 195.113.75.245
  ```
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Current & Future Development
Ongoing Development

- GPU-based LDGM FEC
  - CUDA-based
  - works up to uncompressed 4K
  - extended performance and configuration profiling
  - to be submitted into Future Generation Computer Systems journal
- New implementation of video mixer – with i2cat
  - to avoid OpenGL/GLSL readback performance problems
  - based on OpenCV with OpenCL acceleration
Ongoing Development

- CoUniverse
  - self-organization of complex multi-point scenarios incl. transcoding
  - research work that slowly moves into production
- Reimplementation of the UltraGrid core
  - increased modularity and flexibility
  - better maintainability – C++
Future Development Plans

- Real-time image analysis
  - (semi)automated anonymization
  - domain-specific composition of various images
- OpenCL implementation of CUDA-based algorithms
  - we will start with LDGM
  - complex problem for complex algorithms
- Port of UltraGrid to mobile devices
  - by i2cat
  - starting with Android
- Robust software-based echo cancellation
  - problems with clock drift on sound cards
Selected Papers


Thank you for your attention!

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