Optimized DSP Software • Independent DSP Analysis

Developing Embedded Video Software
(Workshop 310)

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Outline

Workshop Outline

The consumer media device
- The big picture

Developing video software
- Software subsystems
- Data types
- Optimization techniques
- Testing

Trends and conclusions

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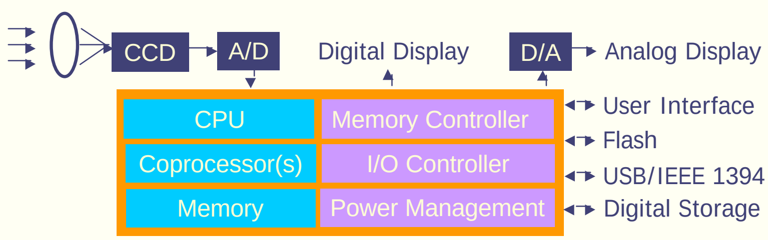
Consumer Media Device: Big Picture

Big Picture

Consumer media devices are complex systems; several software and hardware subsystems:

- Software: Control, video, I/O, RTOS
- Hardware: GPP/DSP, coprocessor(s), DMA, I/O, memory

Siemens press picture



Simplified Model of a Digital Camcorder

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Consumer Media Device: Big Picture

Motivation

- Video moving from hardware to software
  - Processors now have the processing power
  - Moving to software brings many benefits, but…
- Very demanding workloads…
  - Complex algorithms, changing rapidly
  - High computational requirements
  - Stringent real-time constraints

  …stress the processor's abilities
- Creates challenges
  - Optimization
  - Testing

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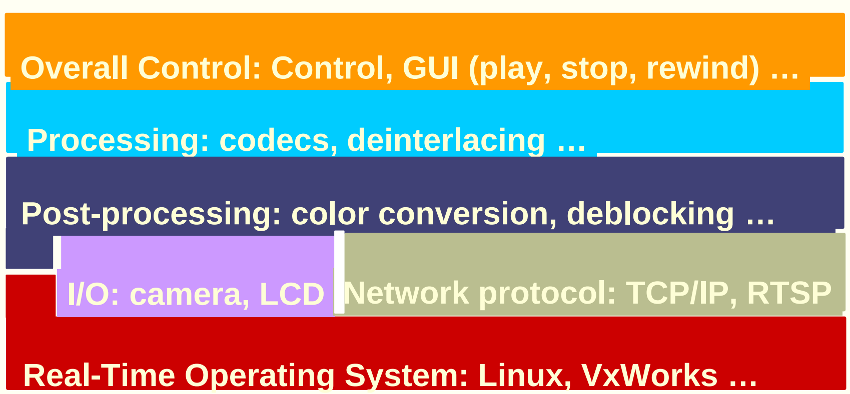
Developing Video Software: Software Subsystems

Software Subsystems

Primary software subsystems include:



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Key Software Considerations

Overall control
- Port to OS and hardware platform

Video processing and post-processing
- Starting point?
- Video data representation
- Optimize for speed, memory use, power, etc.

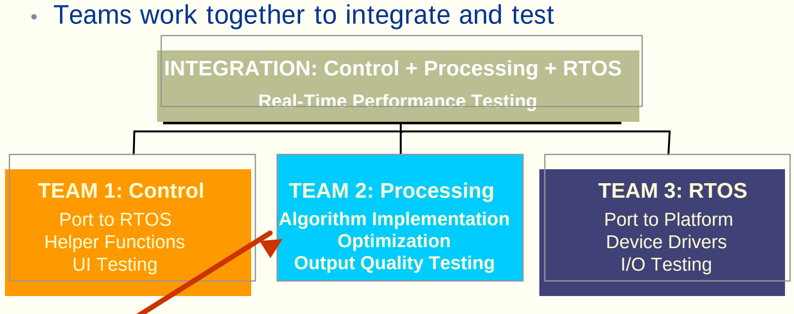
RTOS
- Add/remove features and device drivers

Software integration
- Control + video processing + I/O + RTOS

Testing
- Audio/video quality (test vectors)
- Real-time performance

Software Development

Common division of labor
- Separate teams for groups of related subsystems
  - Teams work together to integrate and test



Hot spot
- Video processing can pose significant development challenges

Developing Video Software: Software Subsystems

Video Software: What's Special?

Not like other kinds of software development:

- Extreme computational demands
- Algorithm attributes
- Data access attributes
- Memory bandwidth requirements
- Testing and validation requirements

- Resource constraints
- Standards
- Real-time requirements
- Reliability
- Specialized and complex processor architectures
- Opportunity for lots of parallelism

→ Optimization is essential! ←

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Data Types

Many important and interesting topics, e.g.,

- **Pixel representation**
- **Image representation**
- Frame stream representation
- **Approximations**
- Error propagation/analysis
- Saturation
- Signal scaling
- Rounding modes

(Focus **topics**)

Pixel Representation

Various ways of encoding a pixel

- RGB (cameras, monitors, and scanners)
- YCbCr, YUV (video codecs, television transmission)
  Separating luminance from chrominance eases compression (chrominance can be down-sampled)

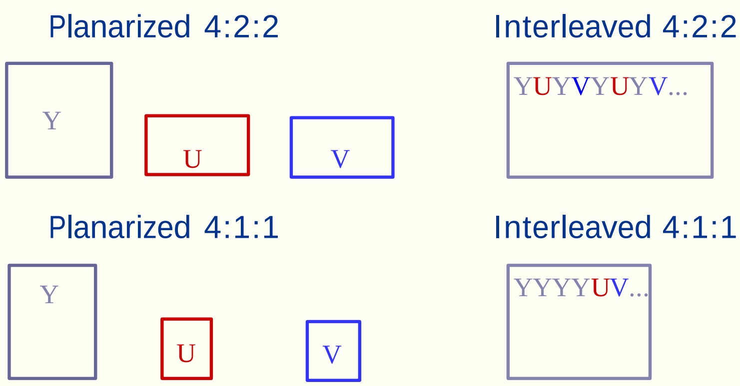
Need for color conversion

- Capture and display video equipment: RGB...
- ...while codecs use YUV
- Color conversion can consume significant processing power
  - 30% to 60% of the cycles needed by the video decoder

Developing Video Software: Data Types

Image Representation

Various ways of encoding color fields



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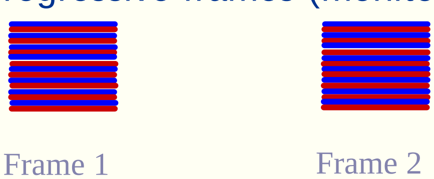
Developing Video Software: Data Types

Image Representation

Various ways of encoding frames

- Progressive frames (monitors, digital TV)



- Interleaved fields (analog TV, most cameras)

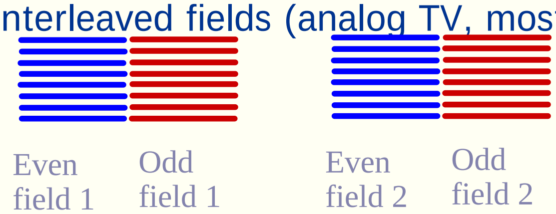


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Image Representation

Choose between planarized and interleaved data representation based on:

- Algorithm(s)
  - Are Y, U, and V data processed independently?
- Architecture
  - What is best the best data arrangement for maximizing parallel execution?
- I/O
  - What options are available for acquisition and rendering of video data?
  - What do standards require?

Developing Video Software: Data Types

Approximations

Dropping video frames

- Can be done occasionally
- More forgiving than audio

Compromising on precision

- Sometimes, processor load can be dramatically lowered by dropping one bit
  - E.g., staying with 8-bit data instead of 16-bit data

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Developing Video Software: Optimization

Optimization Techniques

Optimization process

→Profile → Analyze → Optimize

Optimization levels

- Algorithm level
  - Either processor dependent or processor independent
- **High level language (HLL) level**
  - Relies heavily on the compiler
- Hand-coded assembly language level
  - Yields the best performance

Optimization Techniques

Optimization targets

- Execution speed
  - Using more parallelism
  - **Reducing memory accesses**
    - **Avoid cache, or L1, "thrashing"**
- Memory usage
  - May conflict with optimizations for speed
- Energy consumption
  - Minimize off-chip memory accesses

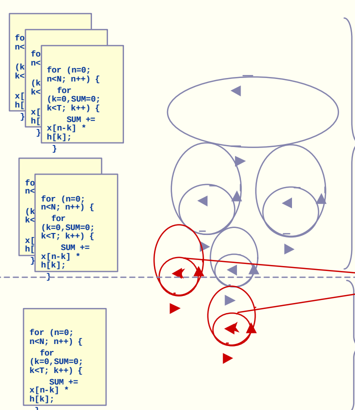
Profiling: Find S-rate Operations

Functions can be classified based on invocation rate:

I-rate (initialization)
< 1 time/sec

K-rate (control)
~10-1,000 times/sec

S-rate (samples)
$\sim 10^4$- 10^{7+} times/sec



~80% of code
~20% of time

Optimization most useful

~20% of code
~80% of time

Developing Video Software: Optimization

High-Level Language Optimizations

- Some processors provide instructions specialized for video. But will the compiler use them?
  - Handling saturation efficiently
    - Saturation instruction intrinsics, look-up tables
  - Handling 8-bit arithmetic efficiently
    - Interpolation, parallel operation intrinsic instructions
- Some reference code uses char data types. But what will compiler do?
  - Handling 8-bit data moves efficiently
    - Packing 8-bit data into 16- or 32-bit words

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Developing Video Software: Optimization

Memory Access Optimization

Video Processing

- Video frame much bigger than typical L1 memory (cache or SRAM)
  - L1: typically 10 to 100 KB
  - Frame: typically 100 KB to 1 MB+ for **each** frame

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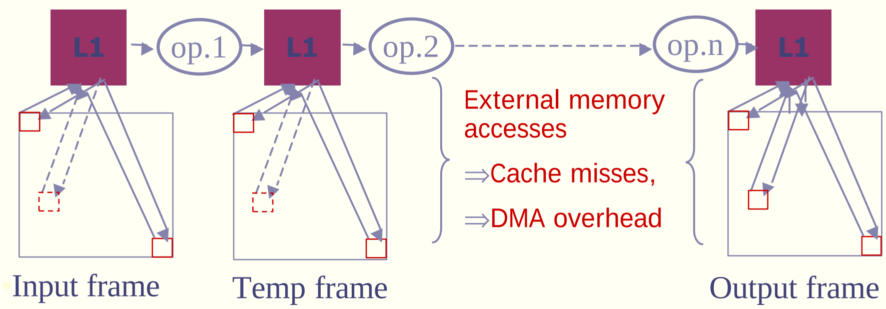
Developing Video Software: Optimization

Memory Access Optimization

Default processing sequence

- Operation 1 on entire frame
- Operation 2 on entire frame…



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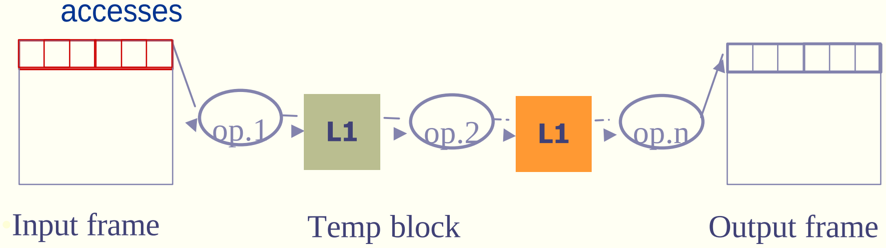
Developing Video Software: Optimization

Memory Access Optimization

Observation: Most video algorithms operate on independent blocks of data (8x8, 4x4, lines …)

Optimization: process one block at a time through multiple algorithm steps

- Subset stays resident in L1, cutting external memory accesses



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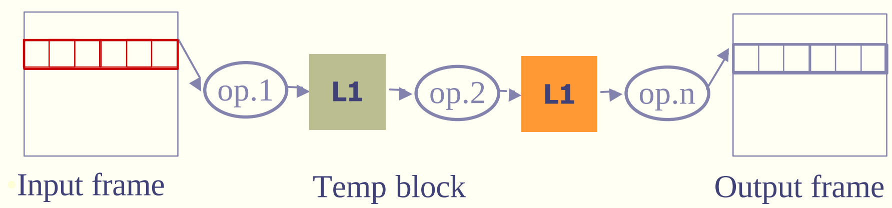
Developing Video Software: Optimization

Memory Access Optimization

Process second block



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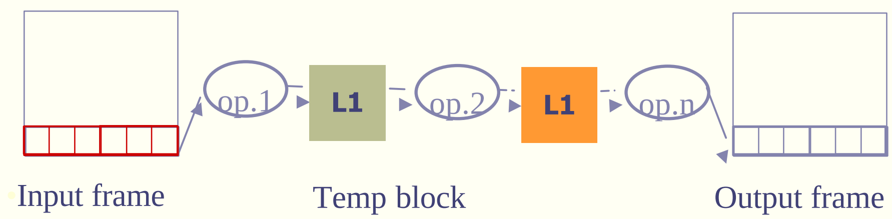
Developing Video Software: Optimization

Memory Access Optimization

Process last block

External memory accesses have been minimized



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Developing Video Software: Testing

Testing

Hardware/development platform
- Challenges with data set sizes

Video processing software
- Operating modes
- Data dependencies
- Output quality

System level (hardware + software)
- Real-time requirements
- Worst-case conditions

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Hardware/Development Platform

Video codecs consume and produce vast amounts of data:

- Compressed bit streams up to ~10+ Mbps
- Uncompressed streams up to 1+ Gbps

Processor simulation model usually far too slow

- Real hardware is needed

Development board must have means to

- Supply large test vectors
- Capture potentially even larger output
  - In digital form for verification

Codec Software: Operating Modes

Video codecs typically have several operating modes

- MPEG-4 video:
  - 21 profiles (18 in part 2 and 3 in part 10)
  - 5 kbps – 1 Gbps bit rates
  - Sub-QCIF to studio resolution
  - Various mixes of I, P, and B frames
  - Progressive and interlaced video

All valid combinations must be thoroughly tested

- Standard reference test vectors probably not sufficient to identify all potential bugs

Codec Software: Output Quality

Difficult to measure quality in context of “lossy” compression algorithms

- Sum of absolute differences (SAD) still most common approximation of codec quality
- Intentionally not bit-exact
- Post-processing algorithms may improve visual quality but deteriorate SNR
  - Deblocking
  - Deringing
  - Sharpening

⇒ Visual inspection of output quality is key

Codec Software: Output Quality

Quality measured:

- Using reference codec and test vectors
- Tests must stress algorithm features...
  - E.g., different motion estimation modes
- ... but also implementation features
  - Fixed-point features (saturation, accumulation, etc.)
  - Various implementation flavors for different sets of parameters (filter size, frame size, etc.)

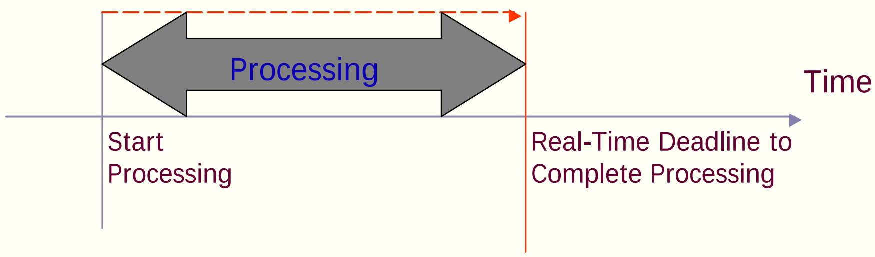
Developing Video Software: Testing

System Level: Real-Time

Real-time performance is not optional

Processor is often underpowered

- Careful codec optimizations can pull underachievers up to real-time performance



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Developing Video Software: Testing

System Level: Worst-Case Loading

Most demanding operating mode

- Highest frame rate and frame size
- Interrupts enabled and active (UI and I/O)

Most demanding data

- Video codecs have data dependent execution paths
  - E.g., pixel, ½-pixel, or ¼-pixel motion compensation
  - E.g., ratios of I, B, P frames
- Algorithms have data-dependent memory accesses
  - E.g., motion-compensated deinterlacing using either data from current frame (cache) or previous frame (ext. memory)

Worst-case performance difficult to identify in video

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Trends & Conclusions

Conclusions

Successful video software development:

- Demands knowledge of the application, algorithms, and processor and mastery of a wide range of skills and tools
- Typically requires aggressive optimization in order to meet tough real-time deadlines
- Requires a well-thought-out testing strategy!

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Trends & Conclusions

Trends

Processors are getting faster and compilers are getting better but

- Newer video algorithms (e.g., AVC) more demanding
- Video processing remains the most demanding task
- Pre- and post-processing increases processor load

Optimized software libraries and hardware accelerators are more common

- Signal processing function level, e.g., IDCT, ME, etc.
- Application level, e.g., MPEG-4 Video Simple Profile

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Trends & Conclusions

Trends

Heterogeneous processors

- Architectures
  - Processor core + programmable logic
  - Multi-processor SoCs
  - Coprocessors
  - Accelerators
- Workload
  - Proposal: off-load compute-intensive S-rate operations to custom logic or specialized processor
  - Reality: inter-processor communications and synchronization overhead can be deadly

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Trends & Conclusions

Trends

Highly parallel architectures

- Architectures
  - MiMagic 6 APA (NeoMagic)
  - Adaptive Computing Machine (Quicksilver)
  - FPGAs (Altera, Xilinx, etc.)
- Workload
  - Proposal: Use many identical processing units to process independent blocks of data in parallel
  - Reality: Some video algorithms do not lend themselves well to parallel implementations (spatial and temporal dependencies)

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For More Information…

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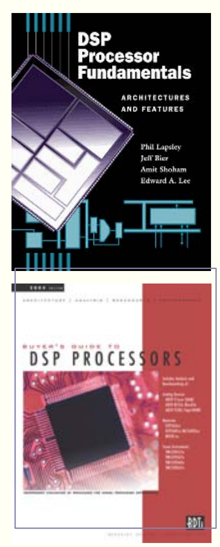
Free Information

- White papers/presentation slides on
  - DSP software optimization
  - Streaming media implementation
  - Processor architectures and performance
  - Digital audio compression
- Article reprints on DSP-oriented processors and applications
  - EE Times
  - IEEE Spectrum
  - IEEE Computer and others
- comp.dsp FAQ



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