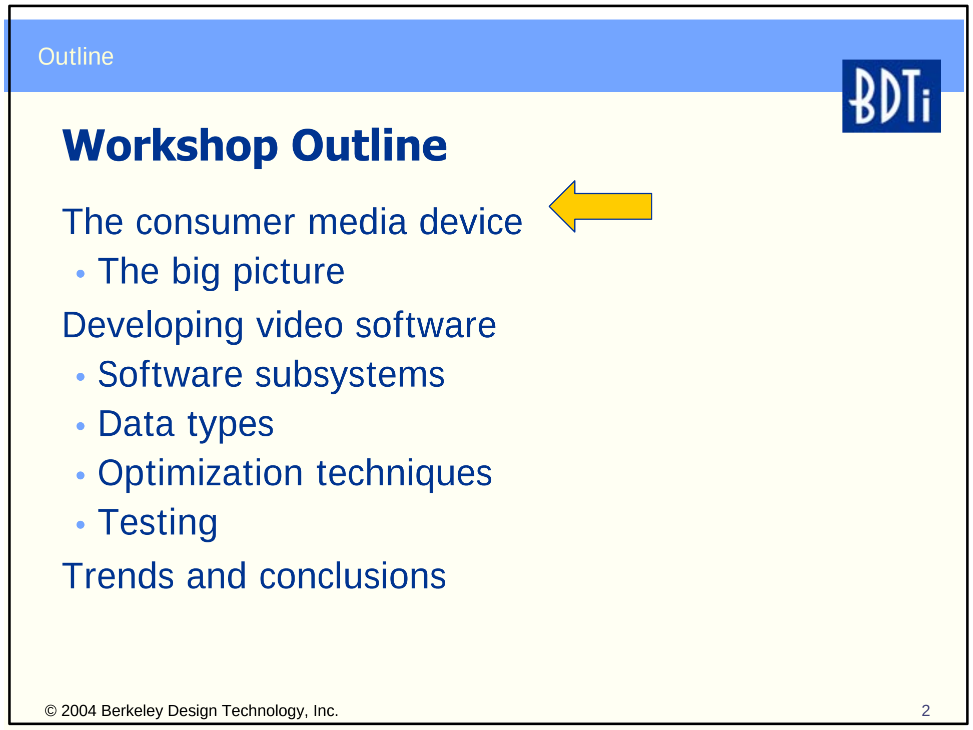
Optimized DSP Software • Independent DSP Analysis

Developing Embedded Video Software
(Workshop 310)

Berkeley Design Technology, Inc.

info@BDTI.com
http://www.BDTI.com



Outline

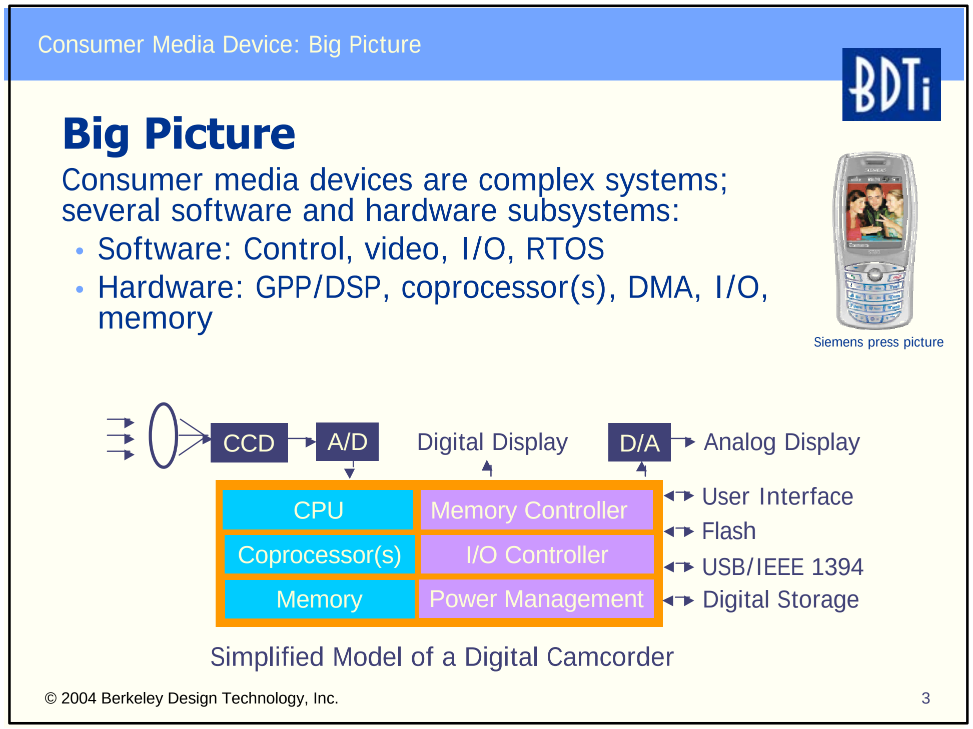
Workshop Outline

The consumer media device
- The big picture

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

Trends and conclusions

2



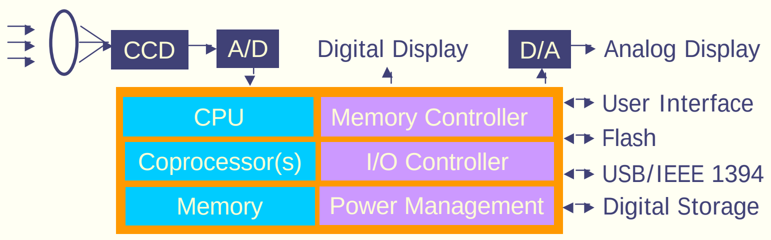
Consumer Media Device: Big Picture

Big Picture

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

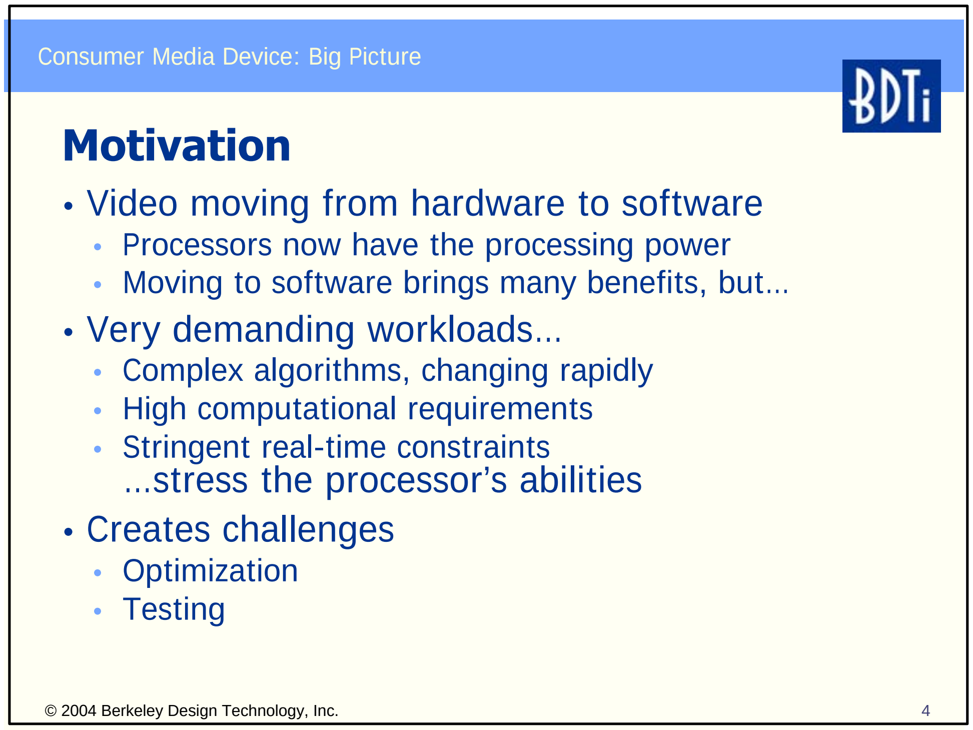
- Software: Control, video, I/O, RTOS
- Hardware: GPP/DSP, coprocessor(s), DMA, I/O, memory

Siemens press picture



Simplified Model of a Digital Camcorder

3



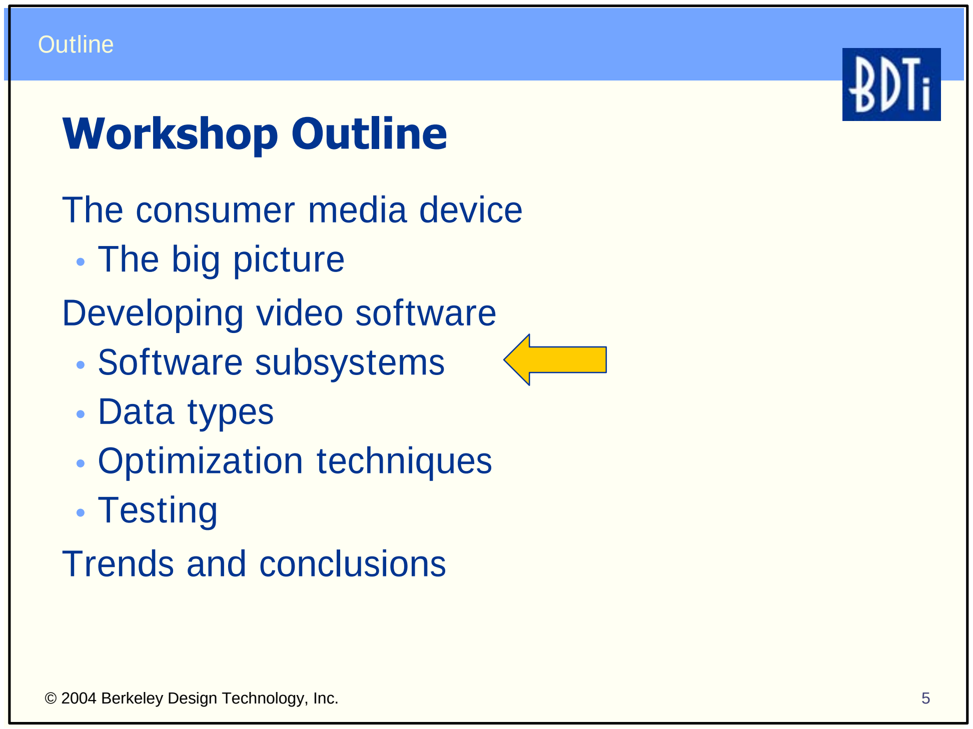
Consumer Media Device: Big Picture

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

4

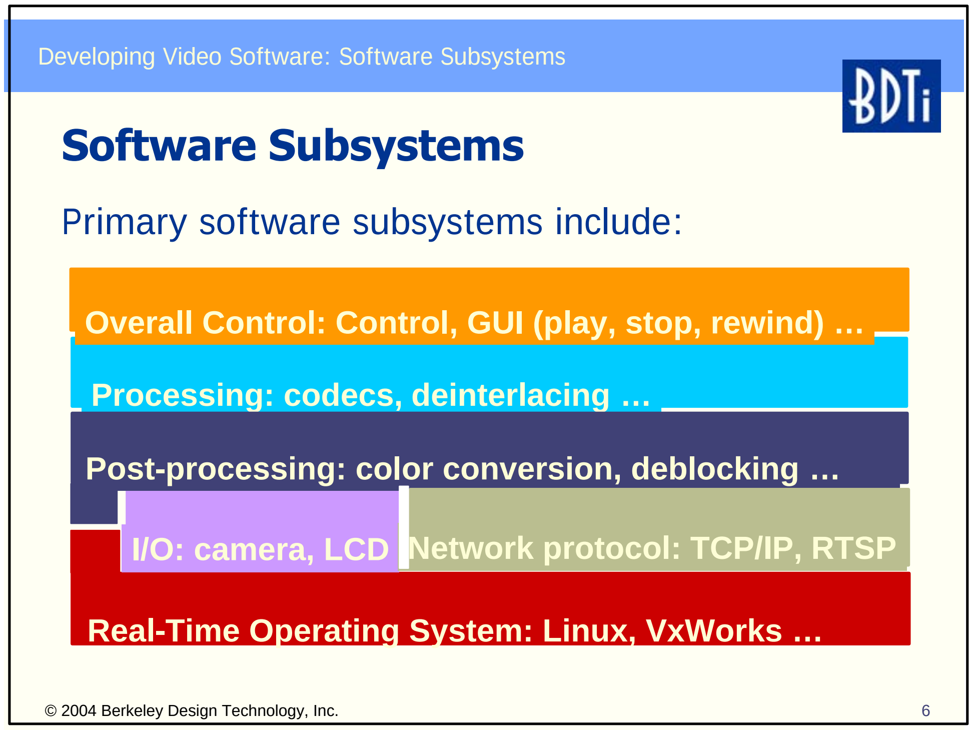


Workshop Outline

The consumer media device
- The big picture

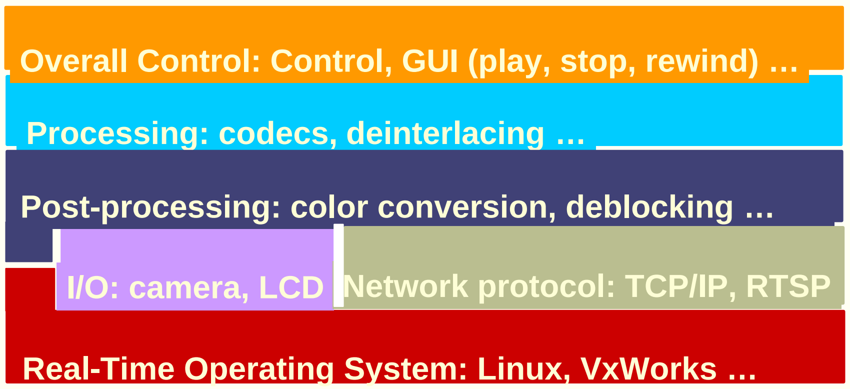
Developing video software
- Software subsystems
- Data types
- Optimization techniques
- Testing

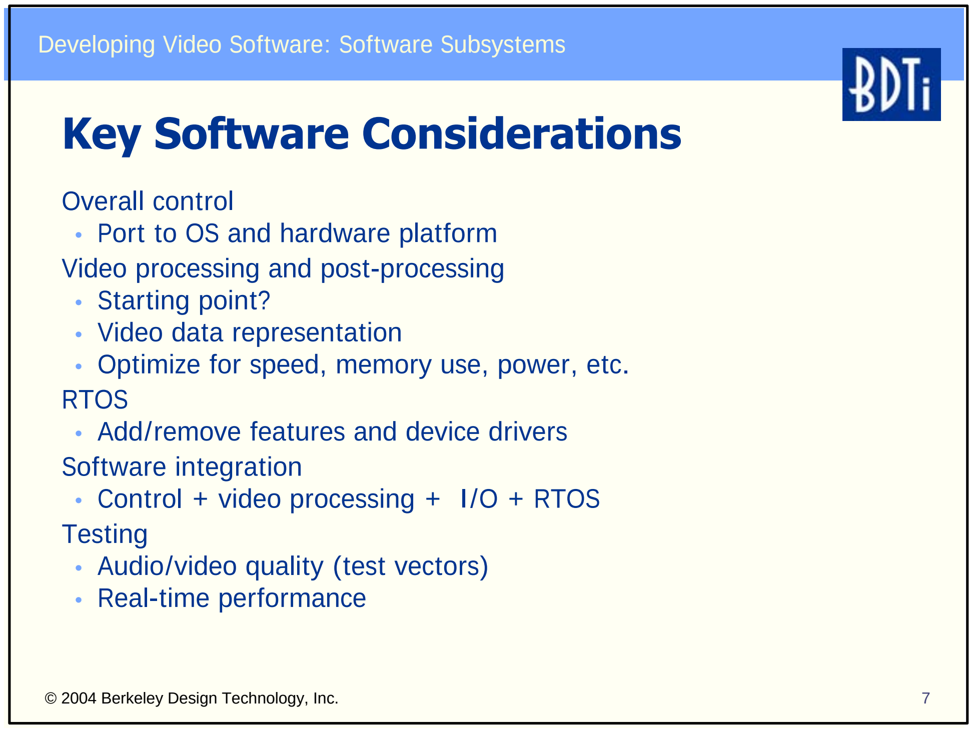
Trends and conclusions



Software Subsystems

Primary software subsystems include:


Overall Control: Control, GUI (play, stop, rewind) …
Processing: codecs, deinterlacing …
Post-processing: color conversion, deblocking …
I/O: camera, LCD
Network protocol: TCP/IP, RTSP
Real-Time Operating System: Linux, VxWorks …



Developing Video Software: Software Subsystems

Key Software Considerations

Overall control
- Port to OS and hardware platform

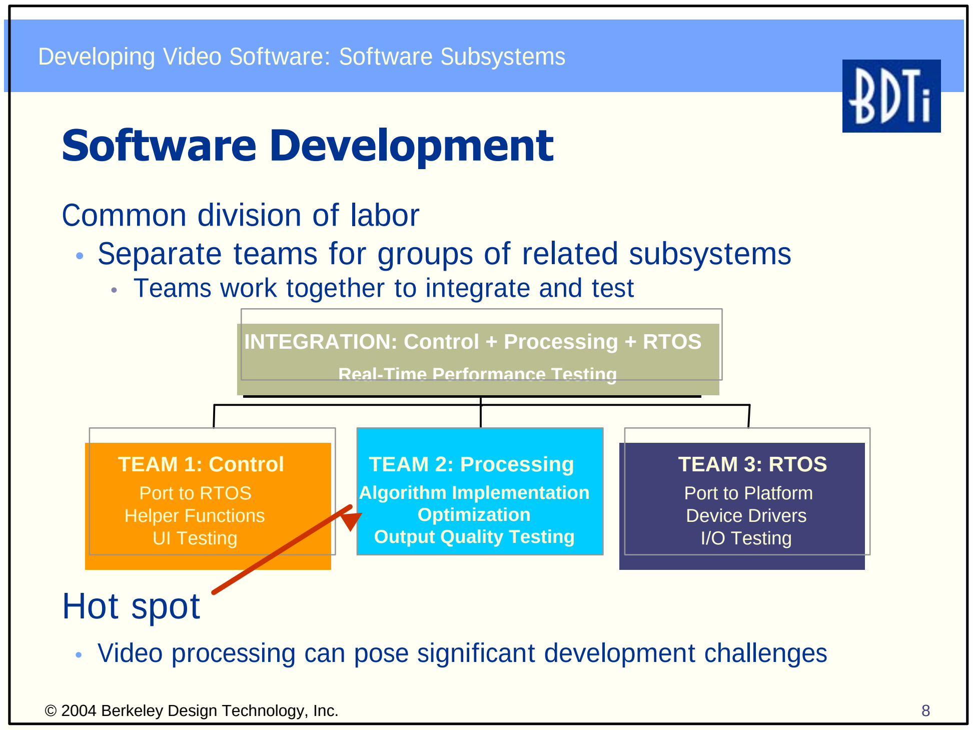
Video processing and post-processing
- Starting point?
- Video data representation
- Optimize for speed, memory use, power, etc.

RTOS
- Add/remove features and device drivers

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

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

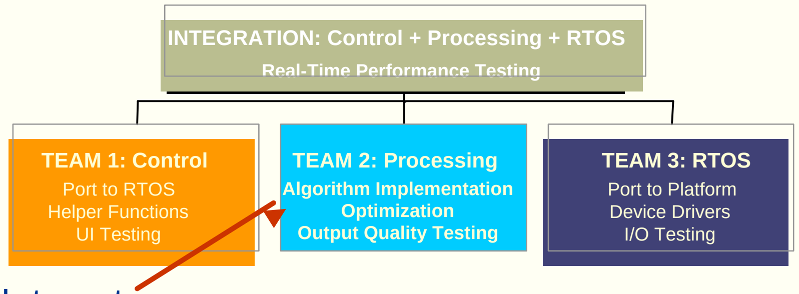
7



Developing Video Software: Software Subsystems

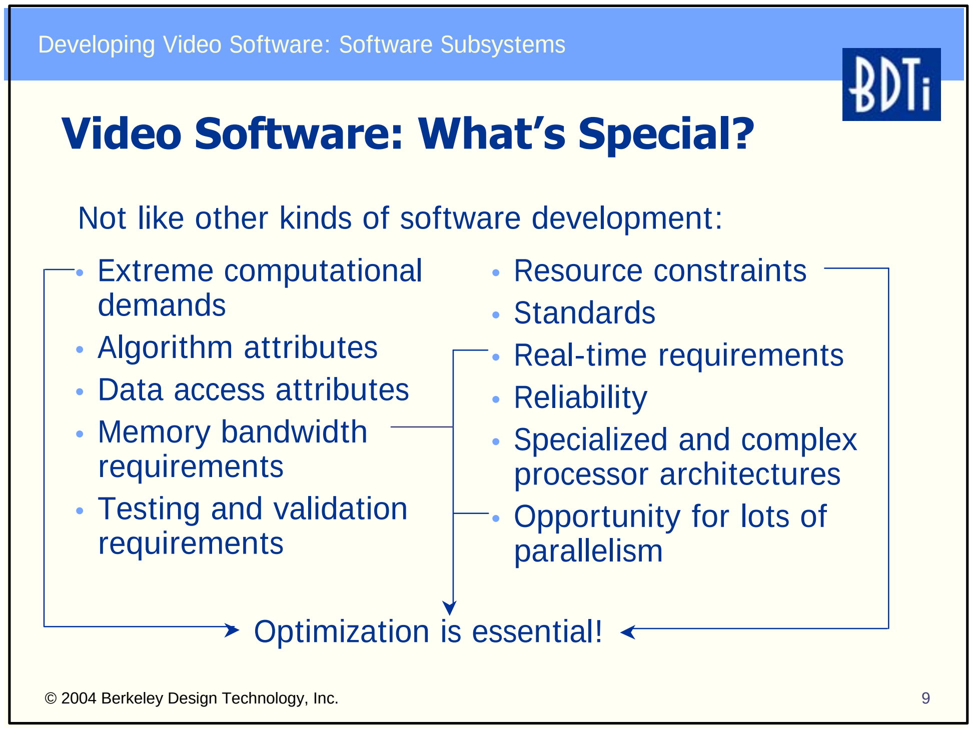
Software Development

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

8



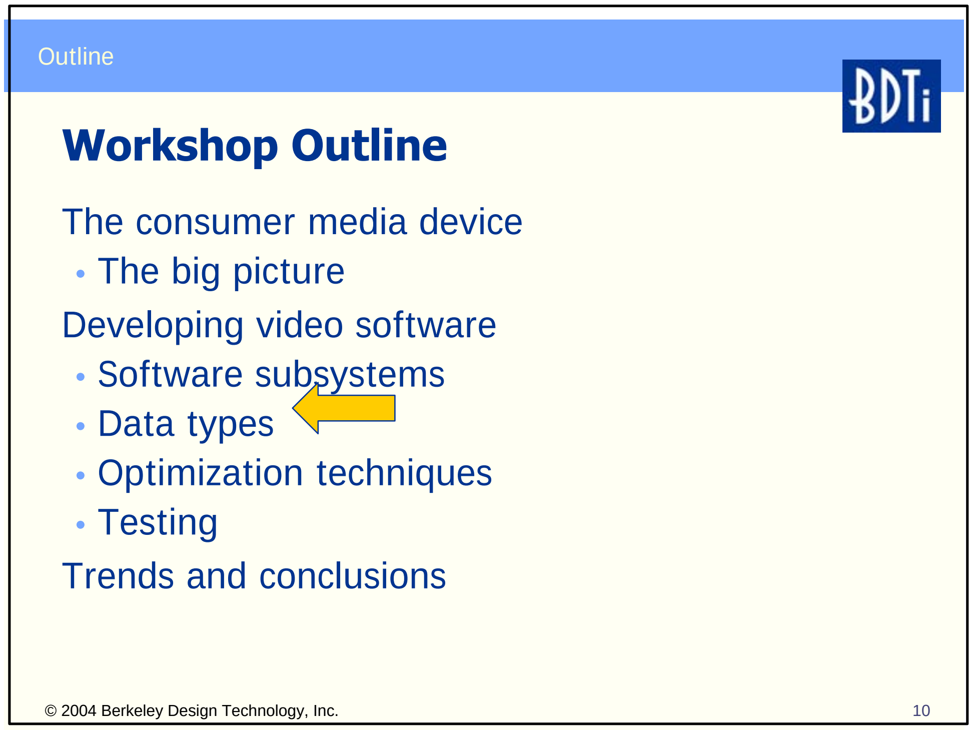
Video Software: What's Special?

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! ←

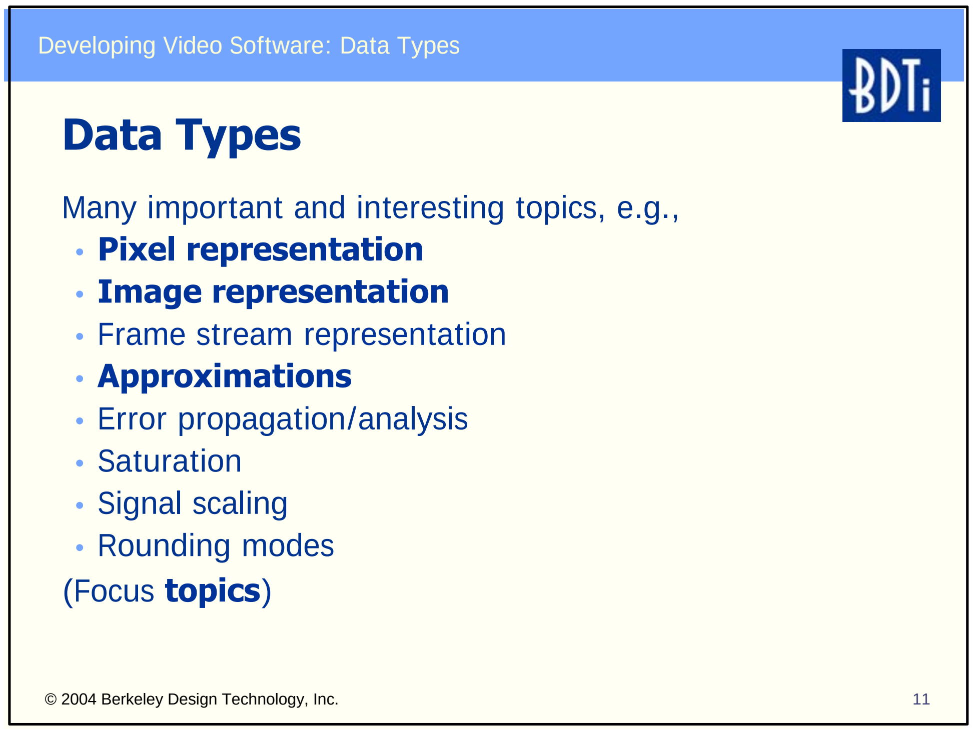


Workshop Outline

The consumer media device
- The big picture

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

Trends and conclusions



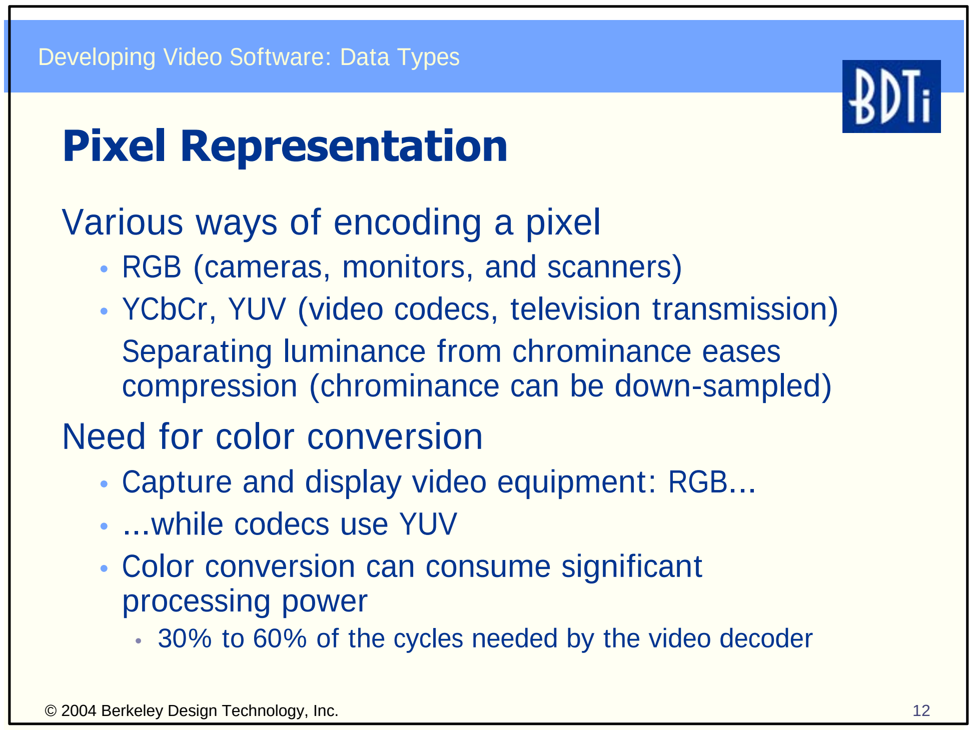
Data Types

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**)

11



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

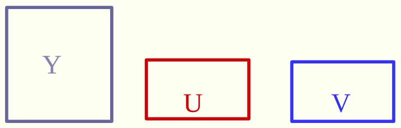
- Capture and display video equipment: RGB...
- ...while codecs use YUV
- Color conversion can consume significant processing power
  - 30% to 60% of the cycles needed by the video decoder

12

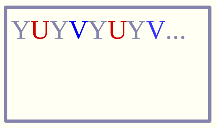
Image Representation

Various ways of encoding color fields

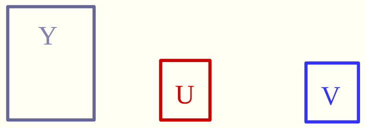
Planarized 4:2:2



Interleaved 4:2:2



Planarized 4:1:1



Interleaved 4:1:1

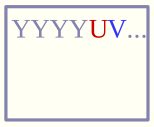
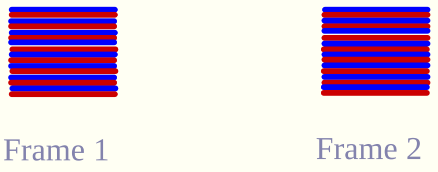


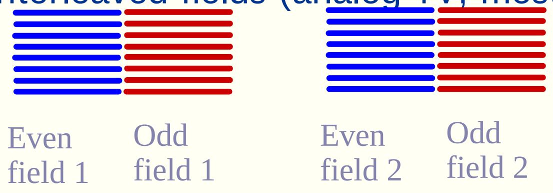
Image Representation

Various ways of encoding frames

- Progressive frames (monitors, digital TV)



- Interleaved fields (analog TV, most cameras)



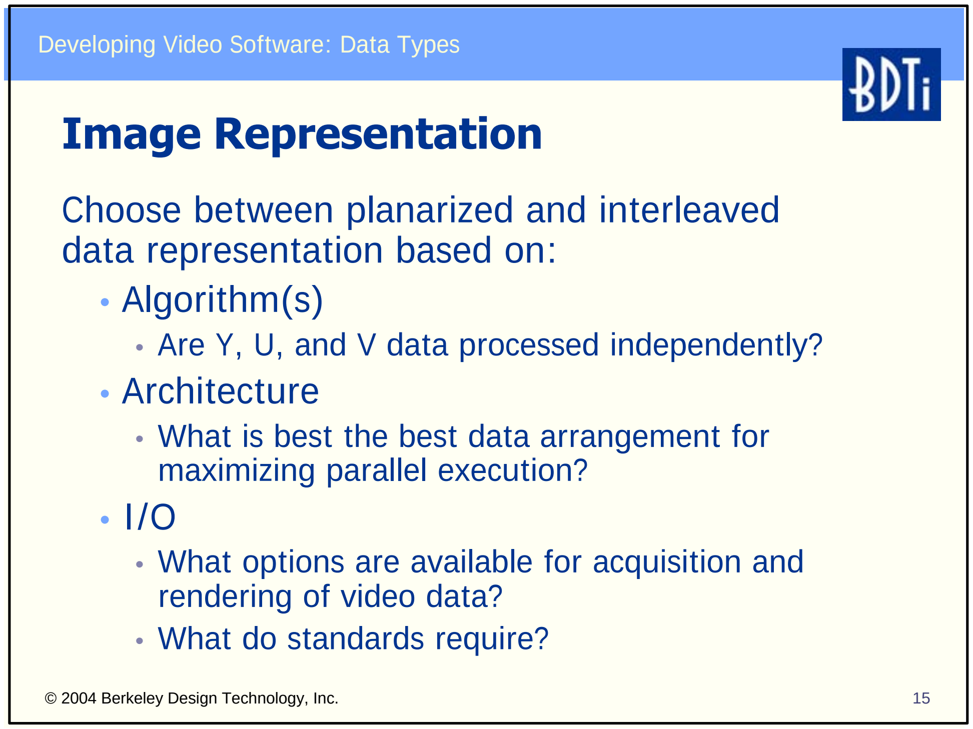
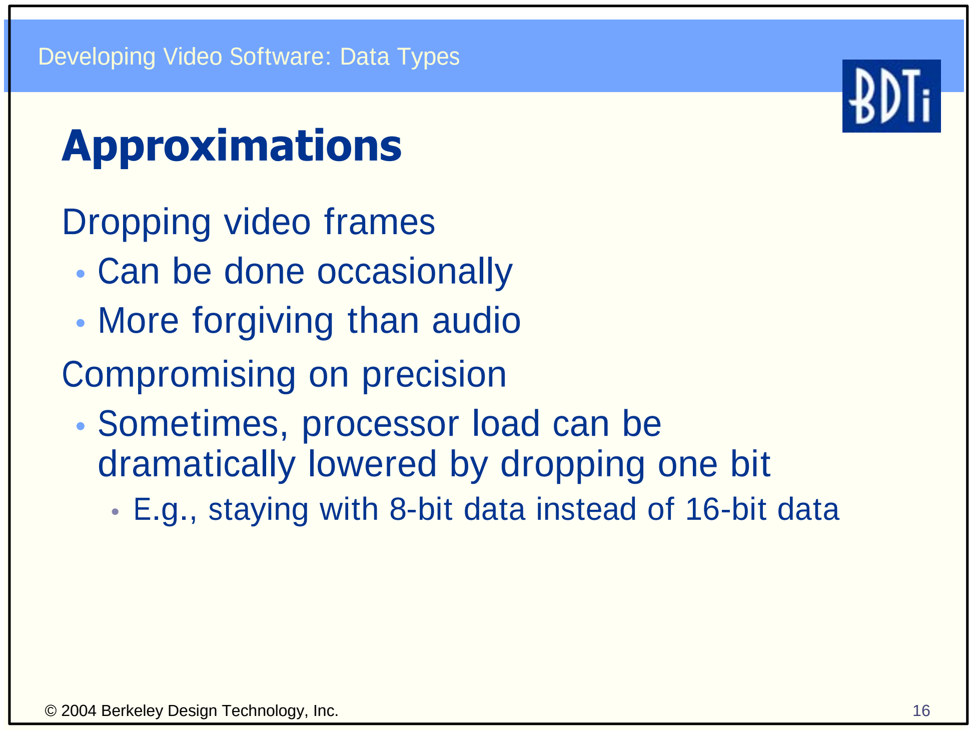


Image Representation

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?



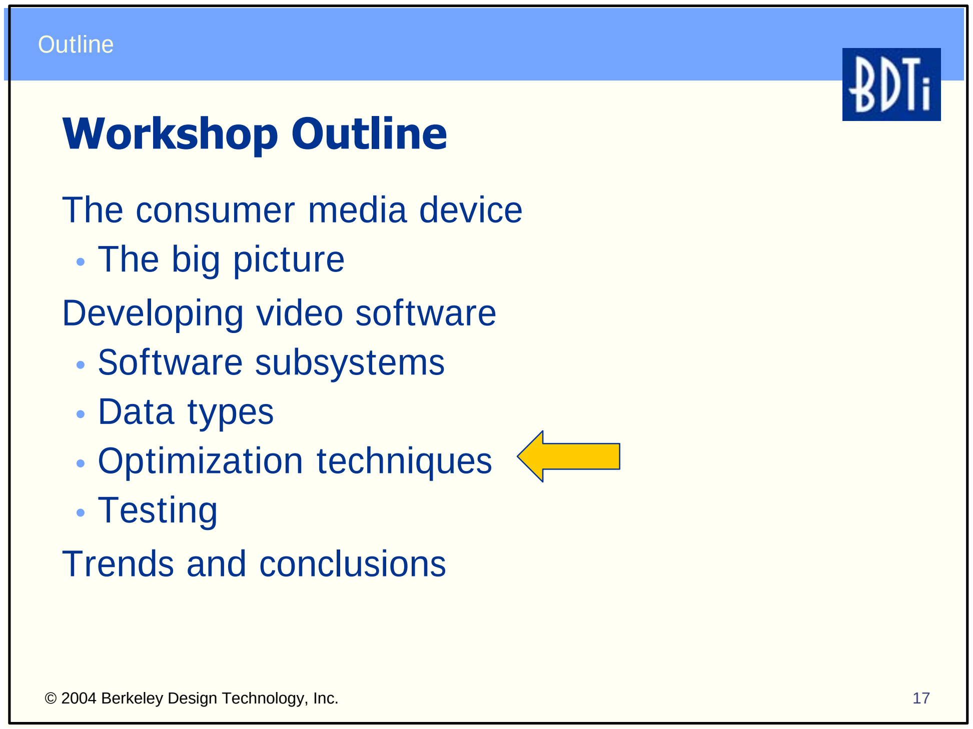
Approximations

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

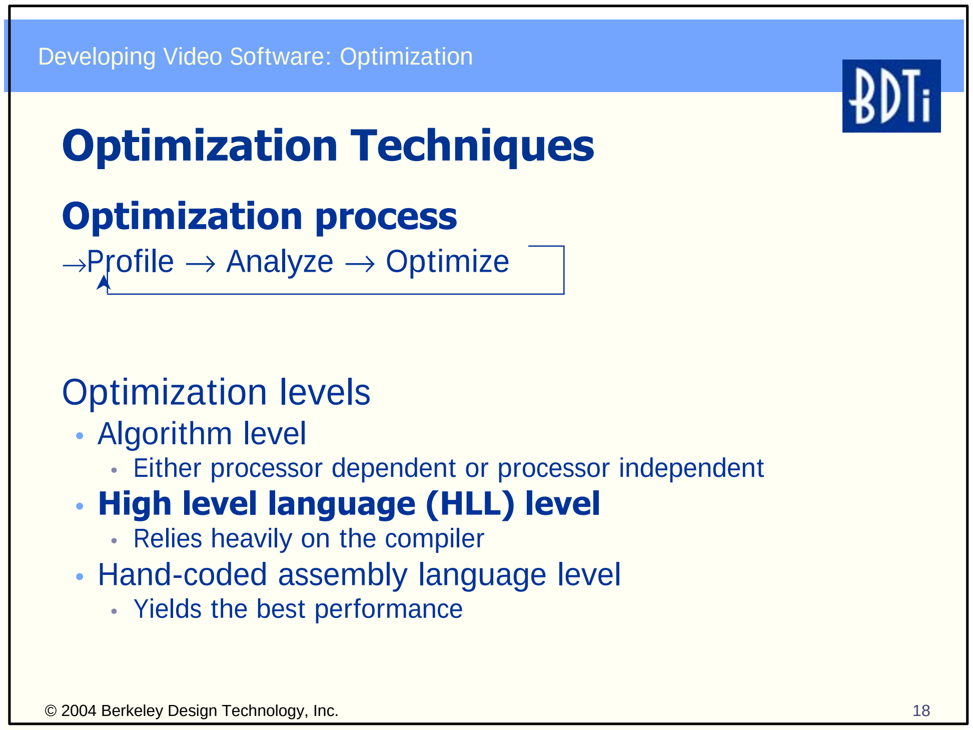


Workshop Outline

The consumer media device
- The big picture

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

Trends and conclusions

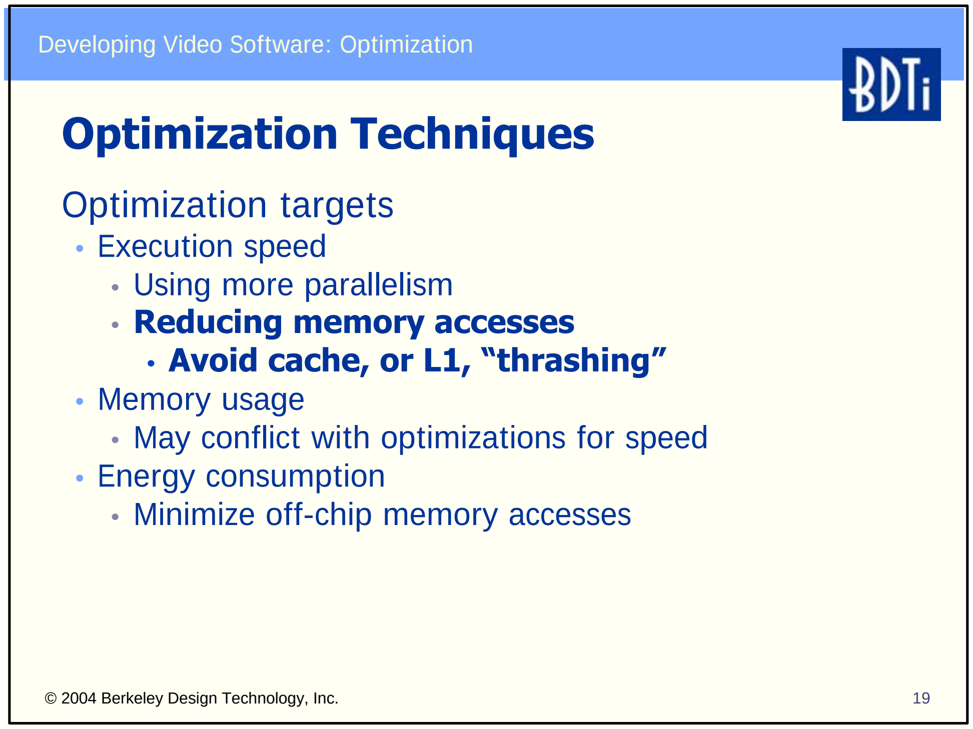


Optimization Techniques

Optimization process

→Profile → Analyze → Optimize

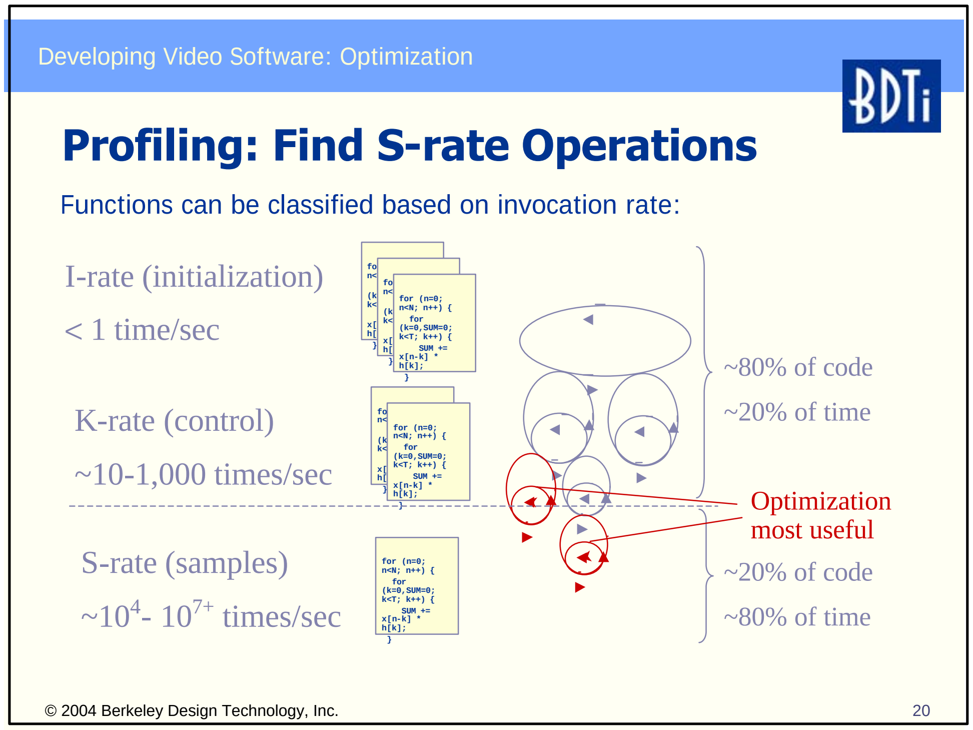
Optimization levels
- Algorithm level
  - Either processor dependent or processor independent
- **High level language (HLL) level**
  - Relies heavily on the compiler
- Hand-coded assembly language level
  - Yields the best performance



Optimization Techniques

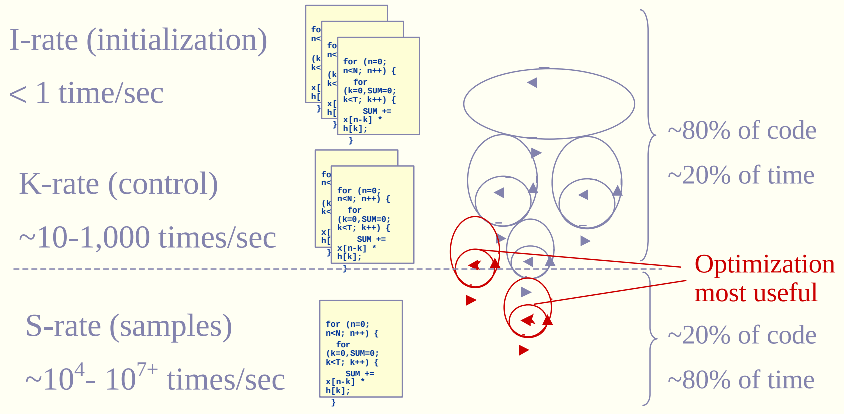
Optimization targets

- 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

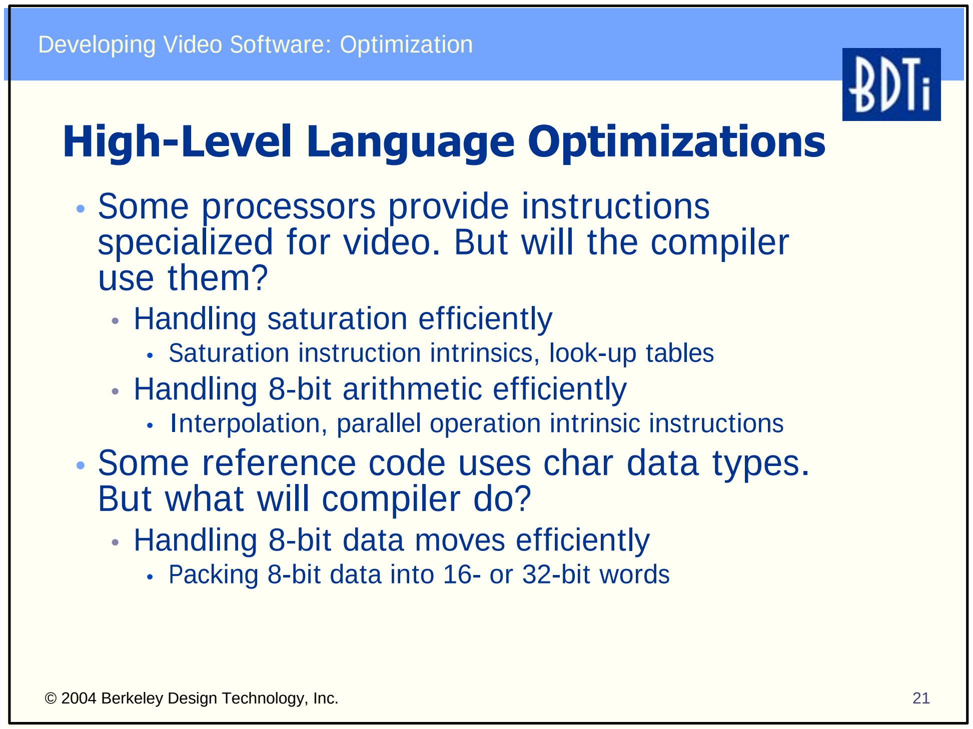


Profiling: Find S-rate Operations

Functions can be classified based on invocation rate:

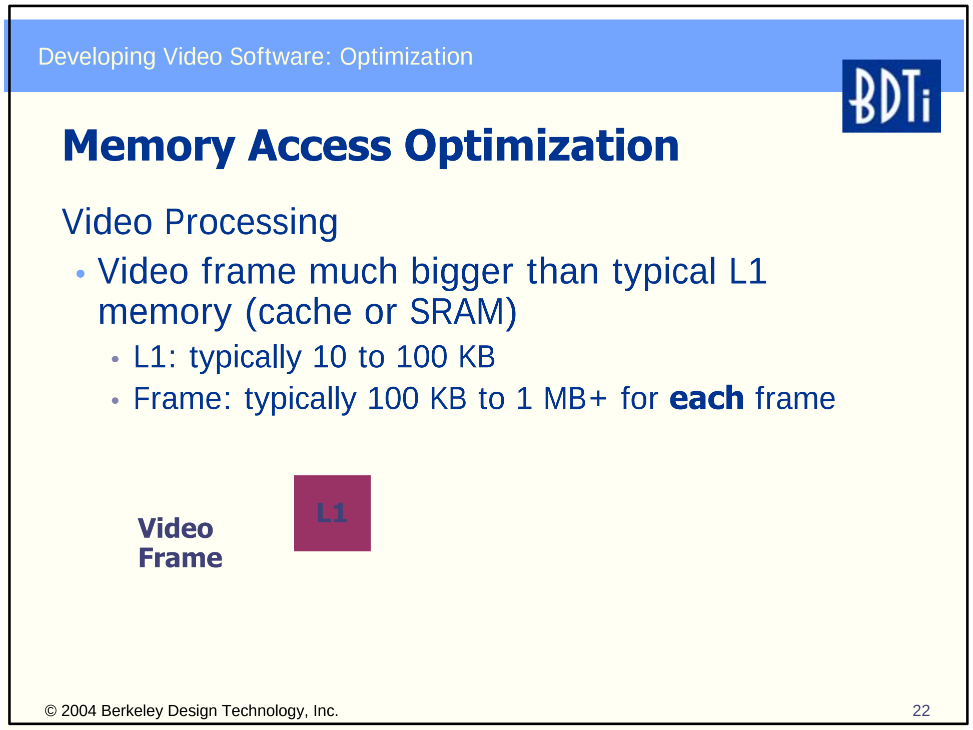


```
for (n=0;
n<N; n++) {
  for
(k=0,SUM=0;
k<T; k++) {
   SUM +=
x[n-k] *
h[k];
  }
```



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



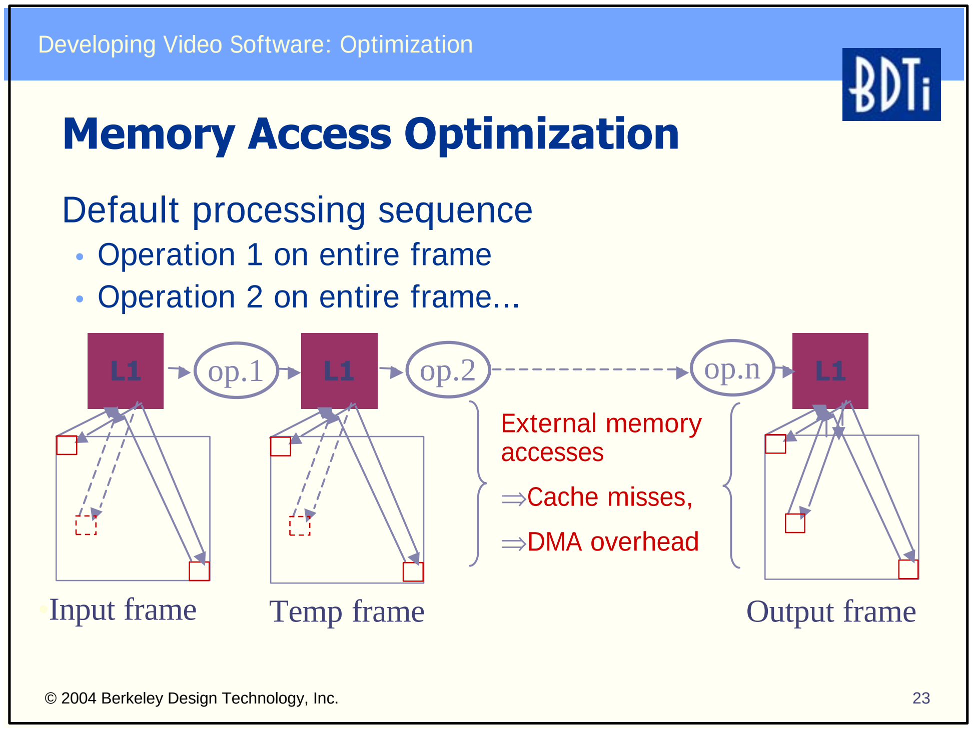
Memory Access Optimization

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

Video Frame

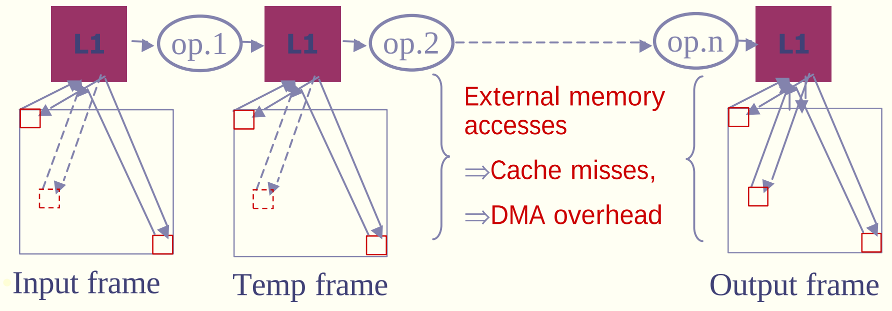
L1

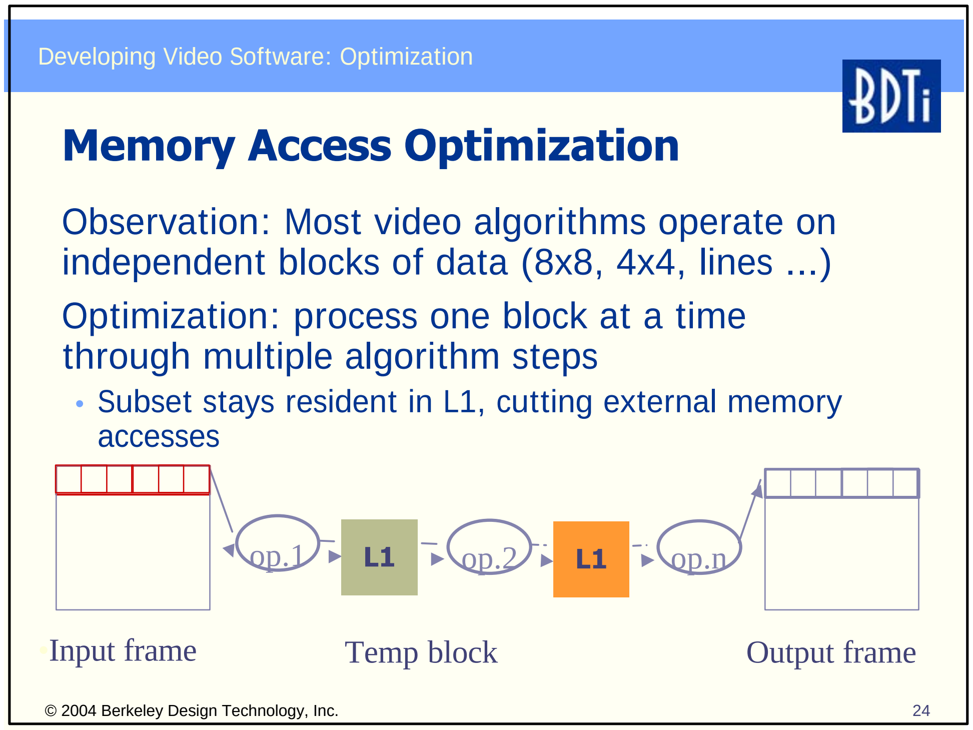


Memory Access Optimization

Default processing sequence

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



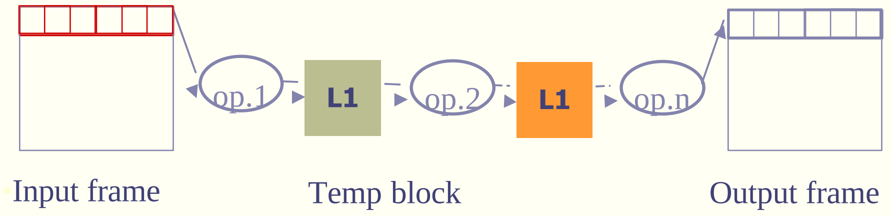


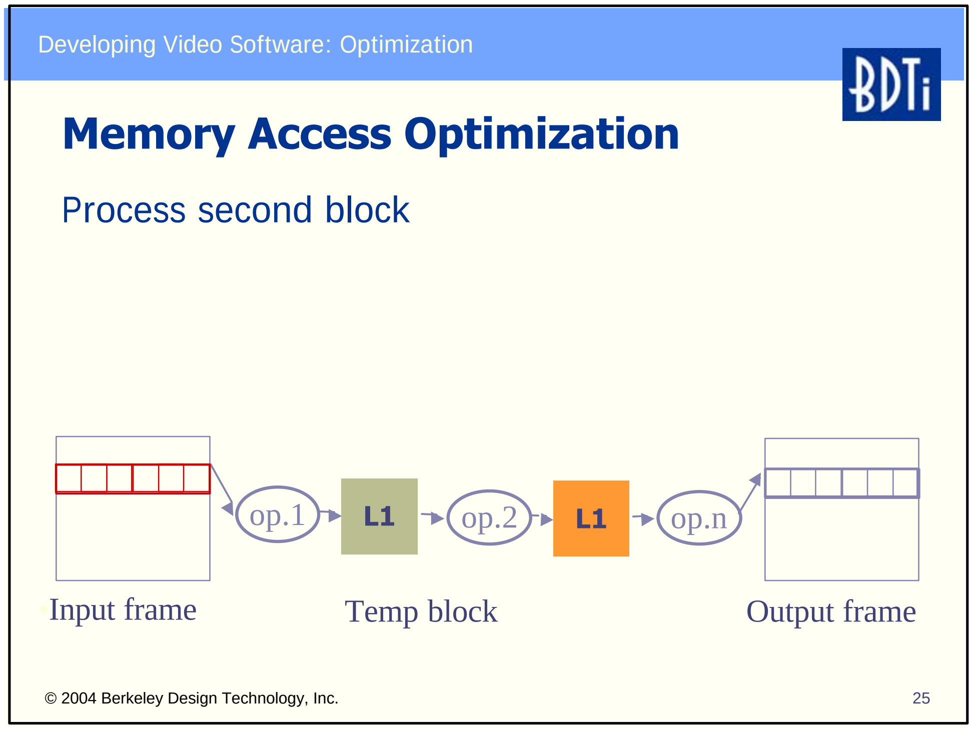
Memory Access Optimization

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

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

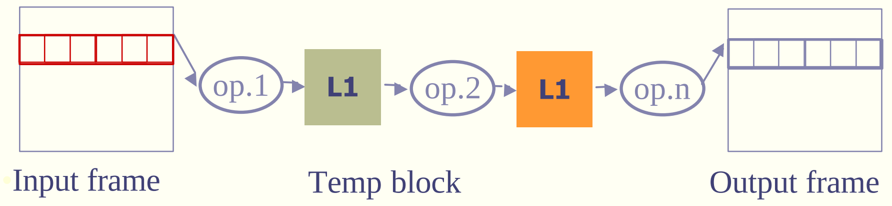
- Subset stays resident in L1, cutting external memory accesses

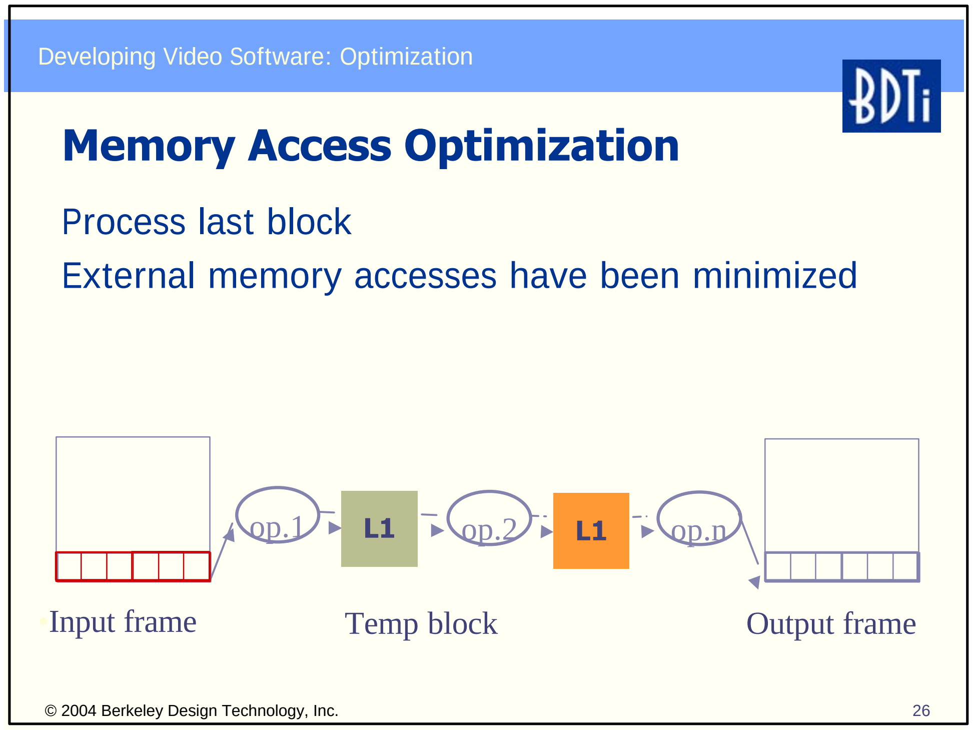




Memory Access Optimization

Process second block

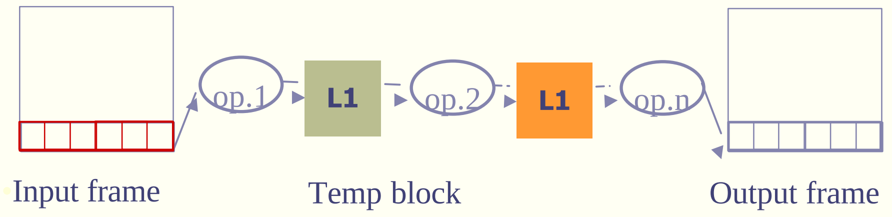


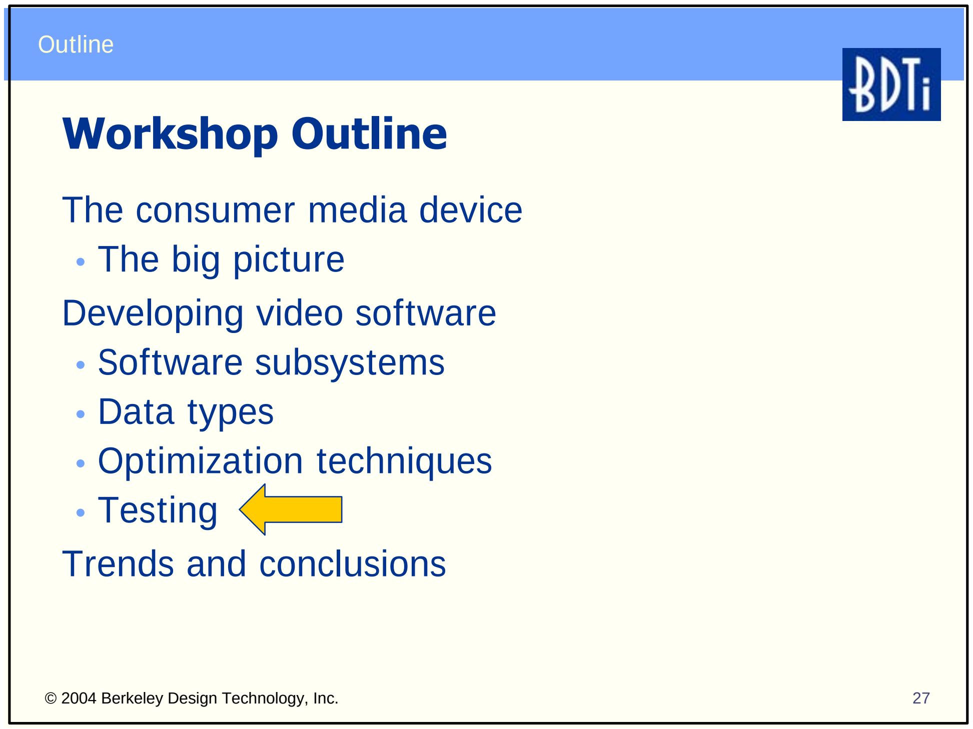


Memory Access Optimization

Process last block

External memory accesses have been minimized



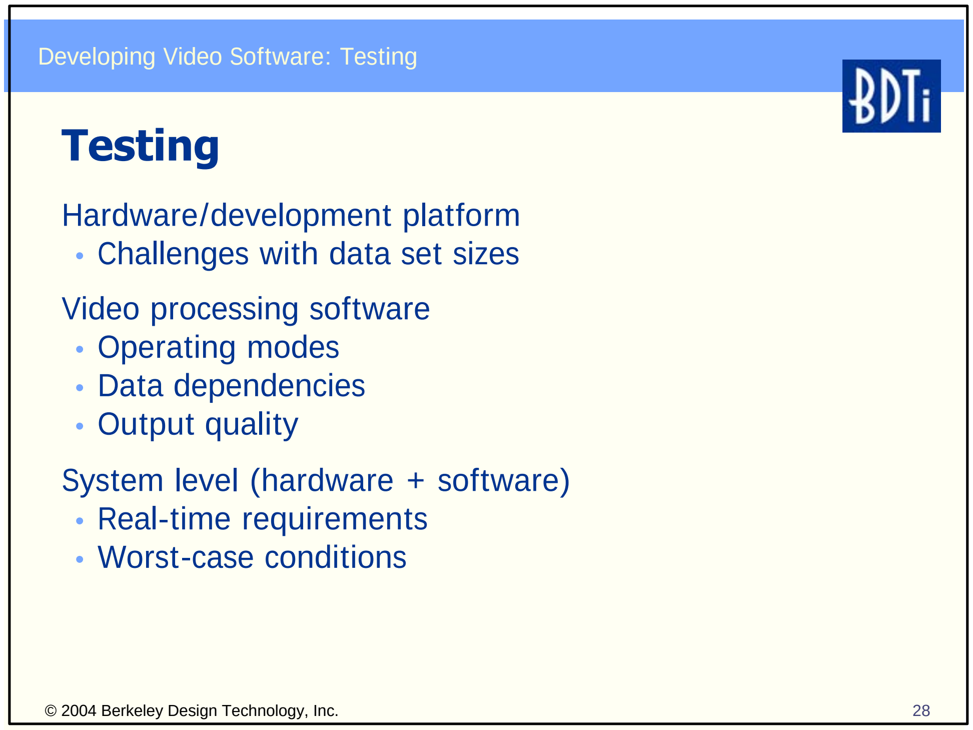


Workshop Outline

The consumer media device
- The big picture

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

Trends and conclusions

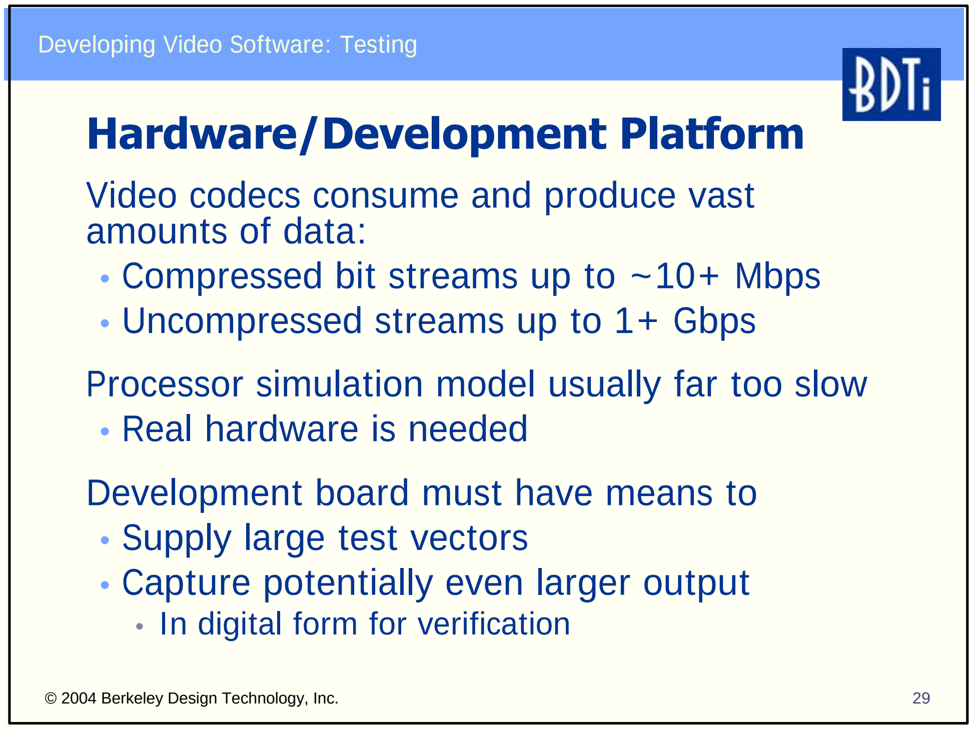


Testing

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



Hardware/Development Platform

Video codecs consume and produce vast amounts of data:

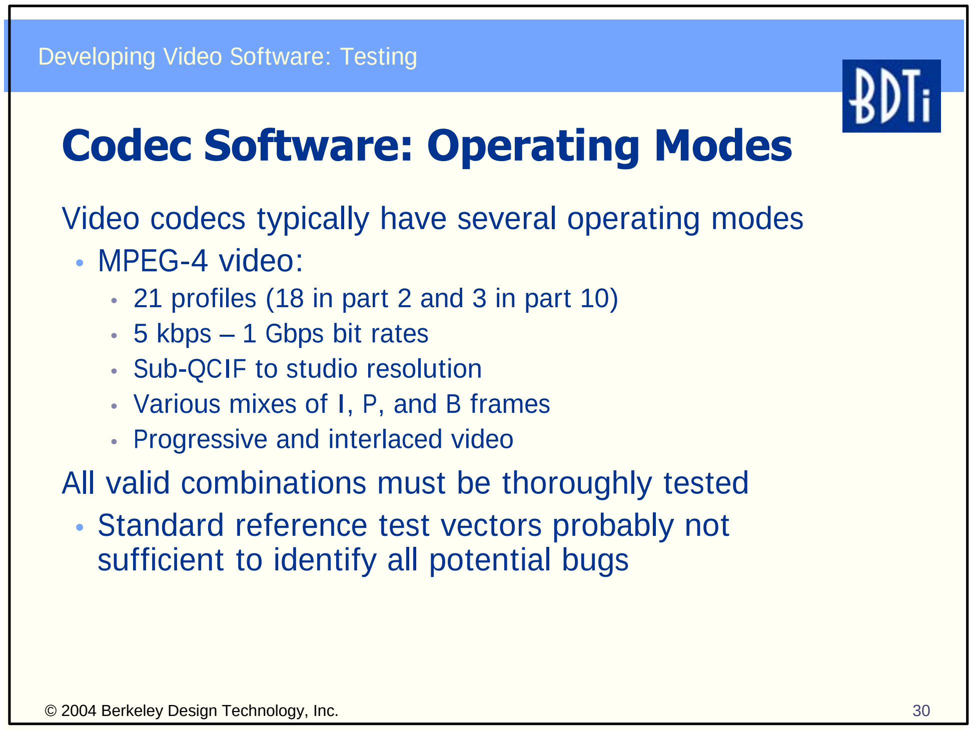
- Compressed bit streams up to ~10+ Mbps
- Uncompressed streams up to 1+ Gbps

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



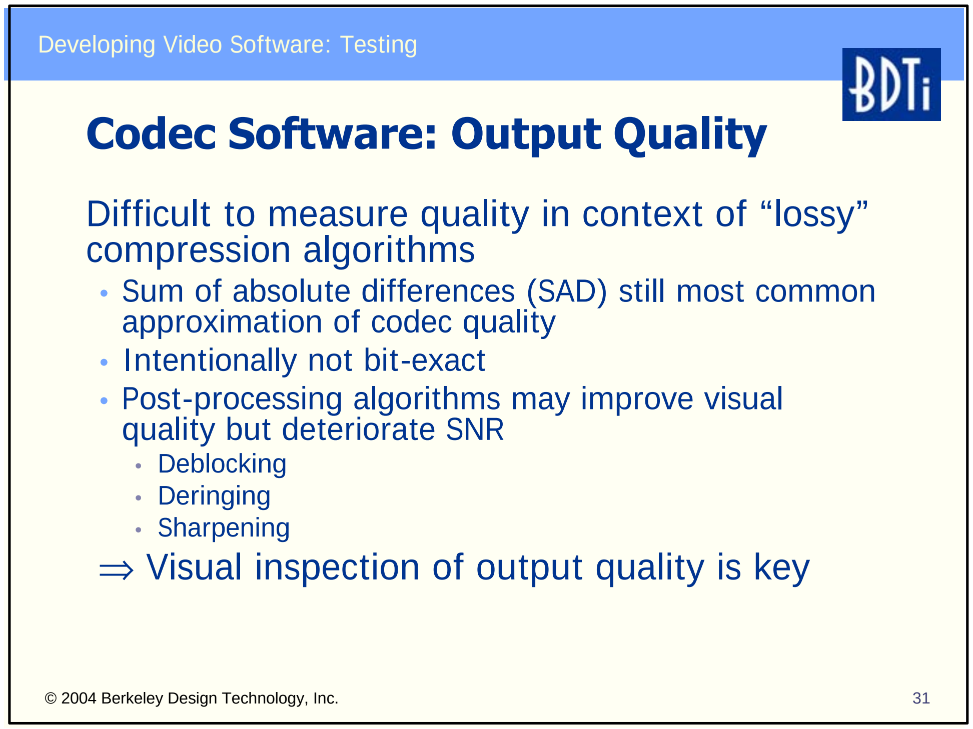
Codec Software: Operating Modes

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

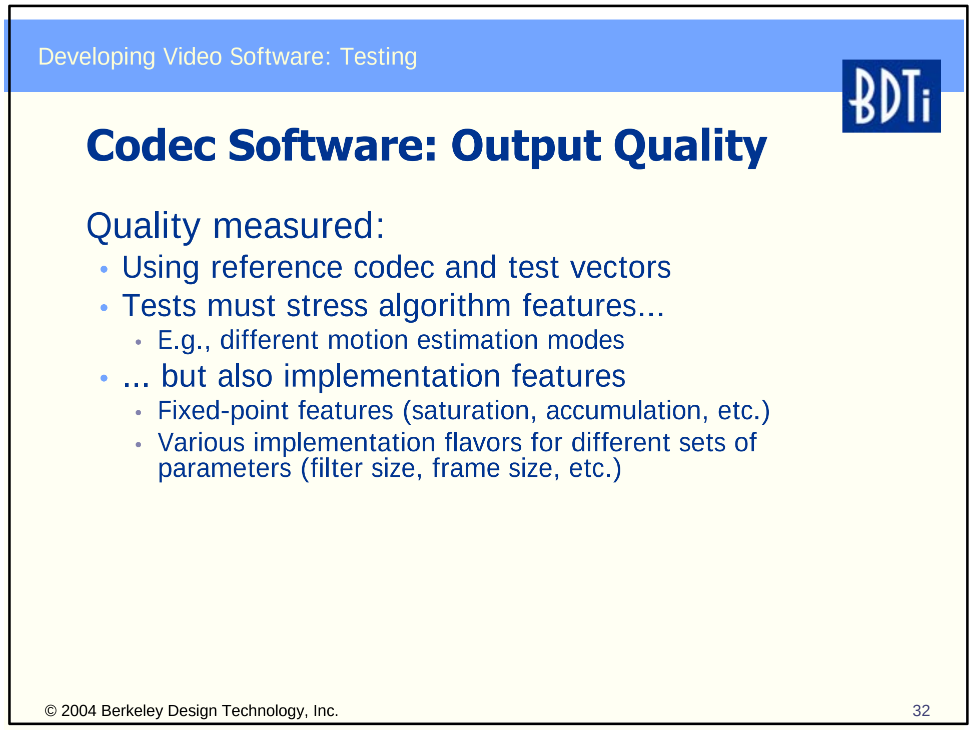


Codec Software: Output Quality

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

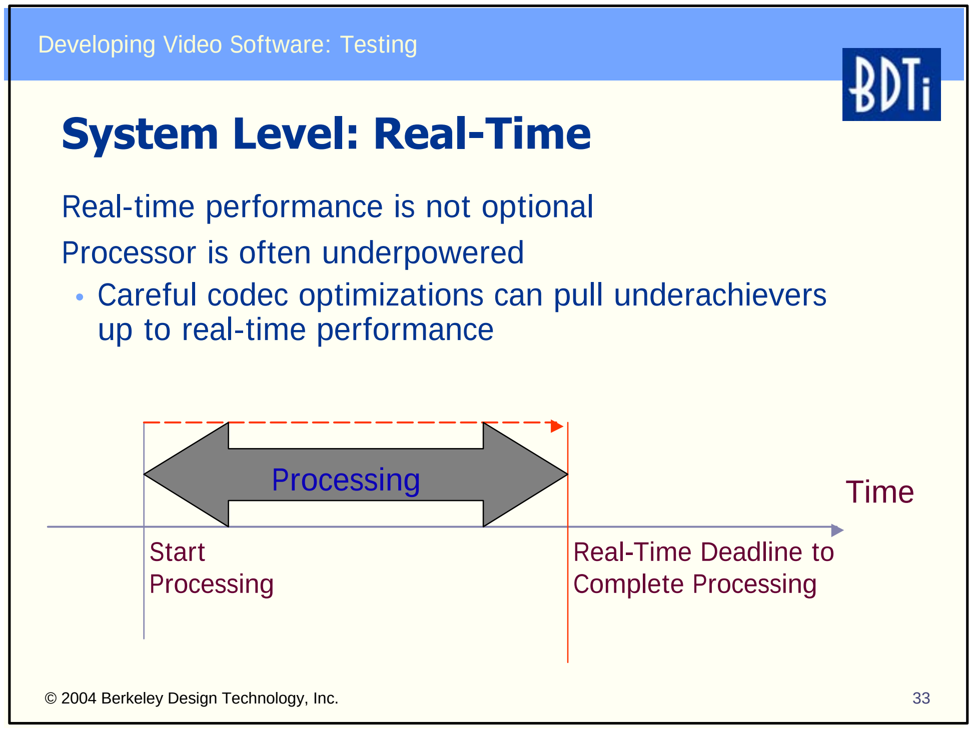
⇒ Visual inspection of output quality is key



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.)

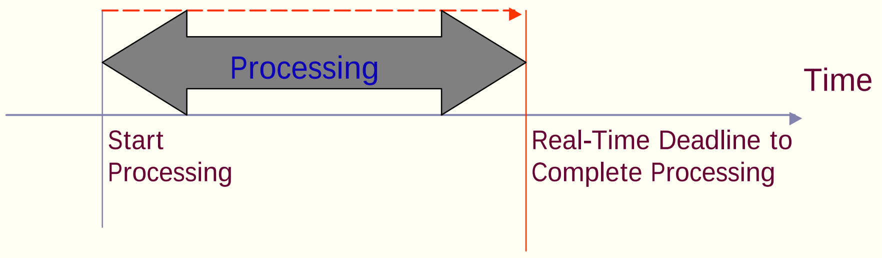


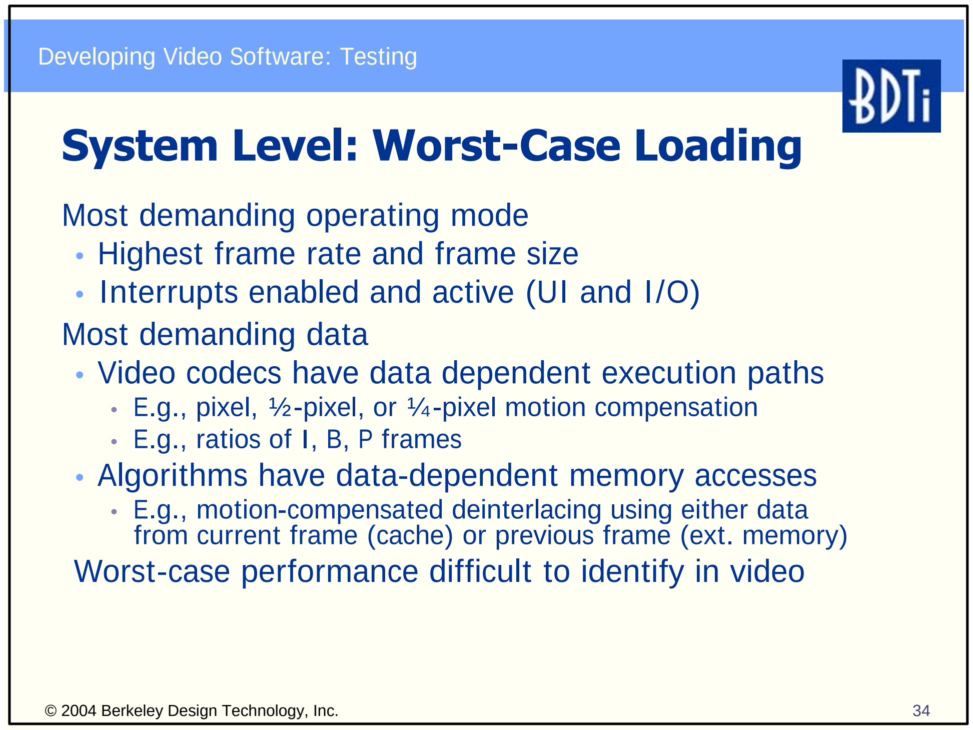
System Level: Real-Time

Real-time performance is not optional

Processor is often underpowered

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





System Level: Worst-Case Loading

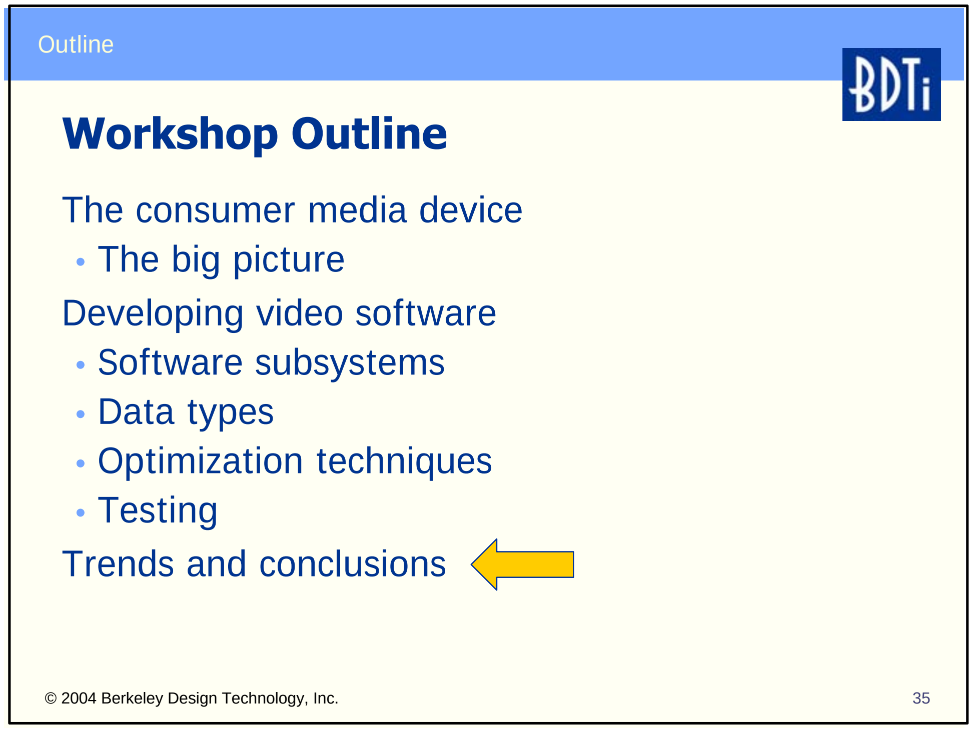
Most demanding operating mode

- 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)

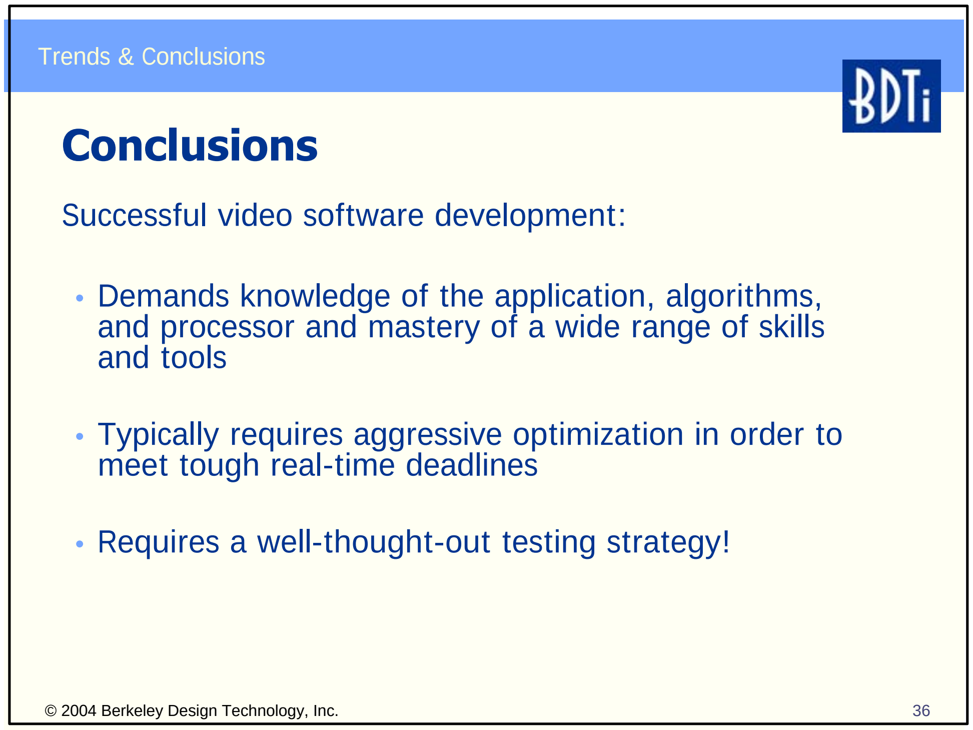
Worst-case performance difficult to identify in video



Outline

Workshop Outline

35



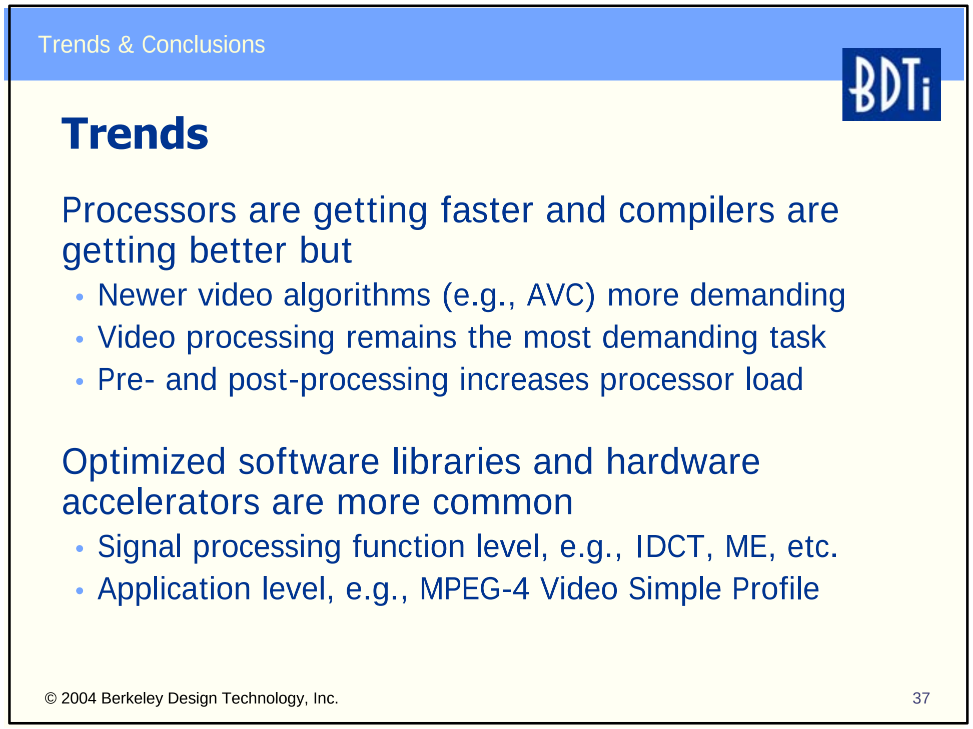
Trends & Conclusions

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!

36



Trends & Conclusions

Trends

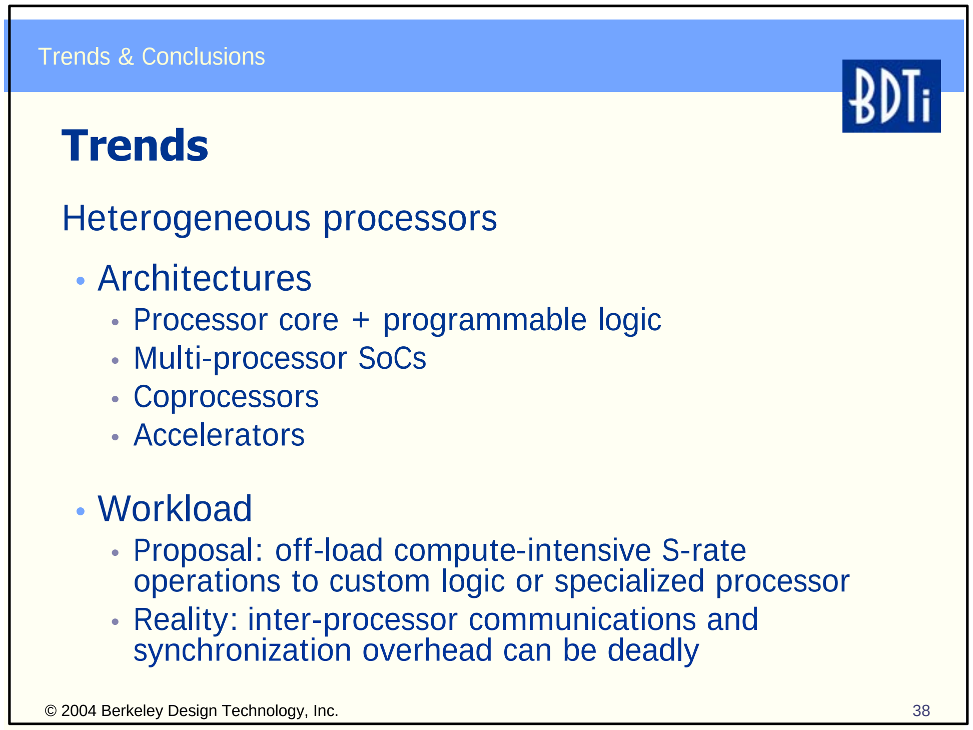
Processors are getting faster and compilers are getting better but

- 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

© 2004 Berkeley Design Technology, Inc. 37



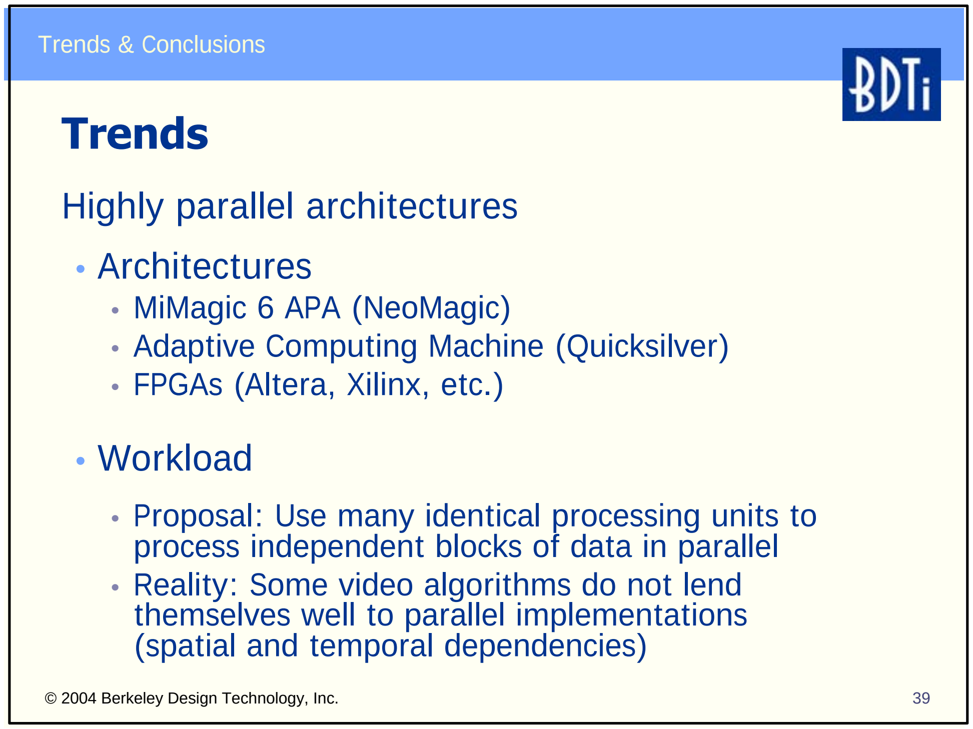
Trends & Conclusions

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

© 2004 Berkeley Design Technology, Inc. 38



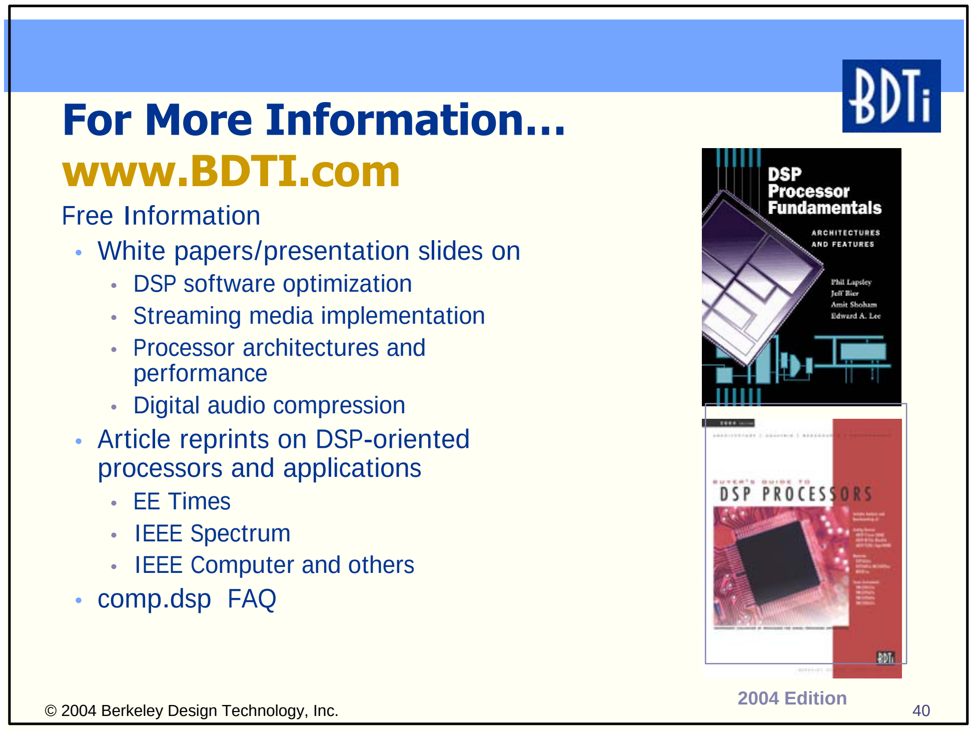
Trends & Conclusions

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)

39

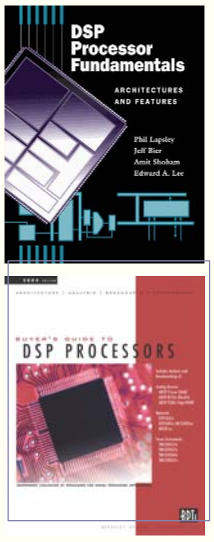


For More Information…

www.BDTI.com

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


DSP Processor Fundamentals
Architectures and Features
Phil Lapsley
Jeff Bier
Amit Shoham
Edward A. Lee
Buyer's Guide to DSP Processors

2004 Edition

40