Insight, Analysis, and Advice on Signal Processing Technology

Processors for Consumer Video Applications

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Outline

- **Motivation and scope**
- Challenges
- Application requirements
- Processor architecture options
- Selection methodology
- Conclusions

 2

Motivation

- Technology creates new opportunities, e.g.,
  - Broadband Internet enables video on demand
  - Product convergence: cellphone+video camera, digital still+video camera
- "Right" processor key to product success
  - Supports, enables desired product features
  - Heavily influences product cost, power consumption, performance (end user experience)
  - Can simplify development effort and cost
- Range of processor options is large and rapidly changing, making selection difficult

 3

Scope

- Processor selection for consumer video products with varying features:
  - Application a mix of video and audio, still image, ...
    - Portable media players, cell phones, still or video cameras, set-top boxes, security, ...
  - Using streaming or stored content
  - Battery or line powered, portable or fixed
  - Cost constrained
  - Input/output quality varies by application
    - E.g., lower quality video for cell phone, high quality video for set-top box

 4

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 5

Processor Selection Challenges

The fundamental problem:

- Many processors and types of processors to choose from
- Complex processors, applications
- Multiple standards to support
- Many important selection criteria to consider
- Unpredictable changes in processor options, application requirements
- Poor information, complex analysis
- Limited time and resources for selection

The wrong choice can be fatal for a product development effort

 6

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 7

Player / DRM Requirements

- Manages other application sub-modules (e.g., codecs), provides user interface
- Processing requirements: 1's–10's MIPS
- Good tools are critical
- Processor features that benefit compilers are useful, e.g.,
  - Orthogonal instruction set
  - Large, linear address spaces
  - Flexible data type support
- I/O bandwidth requirements depend on:
  - Application features, peripheral mix
  - Software architecture

 8

Audio and Video Codec Requirements

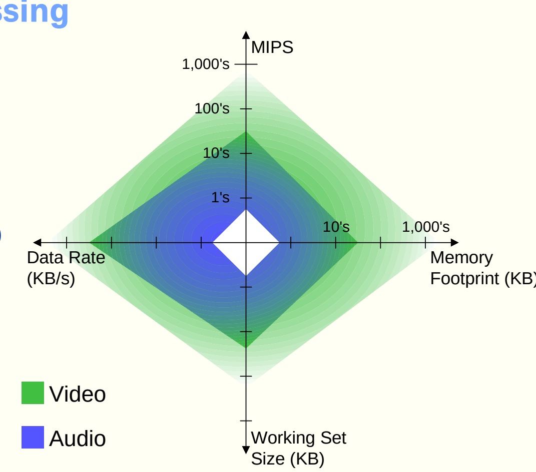
Including Post-Processing

Audio: less demanding

- MP3, MPEG-4 AAC, DTS, RA10 ...
- Sample rate conversion, equalization
- Higher precision (>16 bits)
- Low throughput

Video: more demanding

- MPEG-2, MPEG-4, H.264, WMV9, DivX ...
- Alpha blending, scaling
- Lower precision (≤16 bits)
- High throughput



 9

I/O Requirements

- Processors must support multiple I/O interface standards
  - Basic in-system serial & parallel (CCD, I2S, SPI, “host port”)
  - Storage ports (glueless SDRAM, ATA, flash)
  - External connectivity (Ethernet, USB, 1394, wireless)
- Support for high transfer rates
  - Video data rates range from 100’s—1000’s KB/s
- Autonomous, intelligent I/O
  - E.g., programmable communications coprocessors reduce load on core processor

 10

Development Effort, Cost and Risk

- Development effort, cost, risk affected by many factors
  - Programming model complexity
    - More powerful processor → more complex model
    - More complex model → increased development effort
    - Don't overlook complexity of intelligent I/O
  - Availability of off-the-shelf software components
    - Codecs
    - OSs
    - Device drivers
    - Frameworks
  - Reference designs
  - Quality of tools
    - Maturity, capability of development tools
    - Support for I/O in debug
- The right choice of processor can reduce development effort, cost and risk

 11

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 12

Video Processor Types

Processor Type	*Chips*	*IP*
PC CPU	✓	
Embedded RISC CPU	✓	✓
Application processor	✓	
DSP (generic or specialized)	✓	✓
Media processor, heterogeneous multiprocessor	✓	
Customizable processor		✓
ASIP		✓
Reconfigurable processor	✓	✓
FPGA	✓	
Fixed-function engine	✓	✓
ASSP (incorporating one or more processor types)	✓	

 13

ASSPs

Strengths and Weaknesses

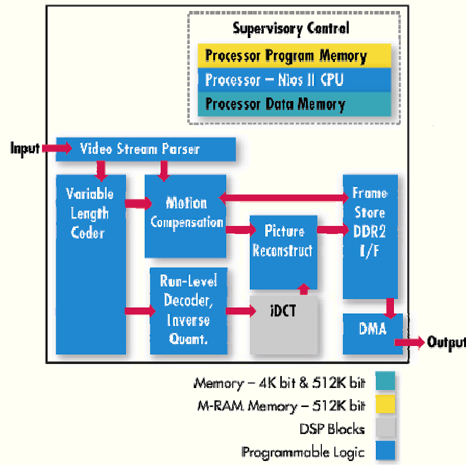
- ⬆ Often very well matched to the application
  - ⬆ SoCs with extensive integration
  - ⬆ Architecture tuned for the application
  - ⬆ Can yield excellent performance, cost, energy efficiency
- ⬆ Ease of use
  - ⬆ Reduce system development costs
  - ⬆ Reduce required implementation expertise
- ⬇ Often inflexible
- ⬇ Limited differentiation opportunities for system designer
- ⬇ Usually single-source
- ⬇ Roadmap often unclear

 14

Example FPGA

Altera Stratix II EP2S15

- Includes specialized fixed-function blocks:
  - Multipliers
  - PLLs
  - Memory blocks
  - High-speed I/O
- Supports Nios II RISC "soft core"
- Real-time MPEG-2 decode (1080p @ 30 fps): 133 MHz
  - Requires ~65% of device
- Price $28, qty 10k
  - Pin-compatible HardCopy II structured ASIC starts at $15, qty 100k



 15

FPGAs

Strengths and Weaknesses

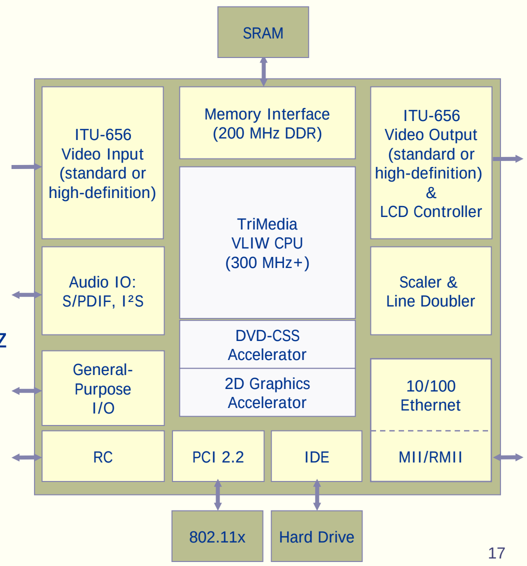
- ⬆ Massive performance gains over instruction set processors on some video tasks
  - ⬆ Huge throughput, cost/performance advantages over DSPs, general-purpose processors in some applications
  - ⬆ Architectural flexibility can yield efficiency
    - ⬆ Adjust data widths throughout algorithm
    - ⬆ Parallelism where you need it; distributed storage
    - Dynamic reconfigurability?
- ⬇ High development effort compared to instruction-set processors
  - ⬇ Complex design flow is unfamiliar to most signal-processing engineers
- Suitability for single-channel, low-power, cost-sensitive applications not proven

 16

Example Media Processor

Philips PNX1500

- General-purpose 300 MHz five-way VLIW
- On-chip L1 data, instruction caches, and L2 data cache
- Media-specific interfaces, co-processors, instructions
- C/C++ programming model
- MPEG-4 decode (simple profile, CIF, 30 fps): 45 MHz
- MPEG-4 D1 video + audio encoding in real time
- Price $15, qty 100k



 17

Media Processors

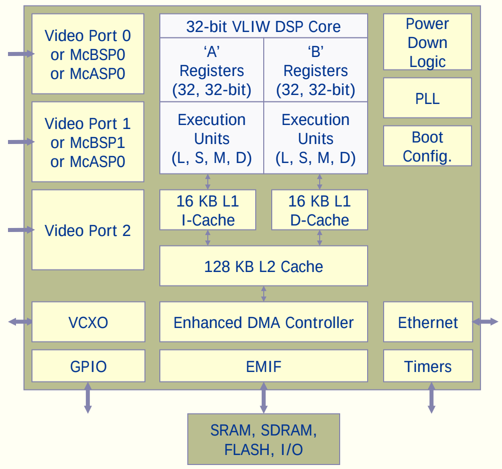
Strengths and Weaknesses

- ⇧ Higher performance than most DSPs, GPPs
  - ⇧ High performance peripherals, coprocessors
- ⇩ Very complex programming models
- ⇧ Better support for video processing in development tools, infrastructure, compared to GPPs
- ⇩ Application performance compiler-dependent
  - ⇩ Compilers can be poor quality
- ⇨ Maturing technology—but roadmaps unclear
  - ⇩ 3^{rd} party support weaker than other processor types
- ⇧ Development cost, risk, lower than ASIC, FPGA

 18

Example DSP Processor
Texas Instruments TMS320DM641

- 600 MHz, 32-bit VLIW DSP processor
- 64, 32-bit general-purpose registers
- 8- and 16-bit SIMD
- Large L1/L2 caches
- High integration
- BDTImark2000™ score: 5480
- MPEG-2 decode (D1 @ 30 fps) under 150 MHz
- Price $30, qty 10k



 19

DSP Processors
Strengths and Weaknesses

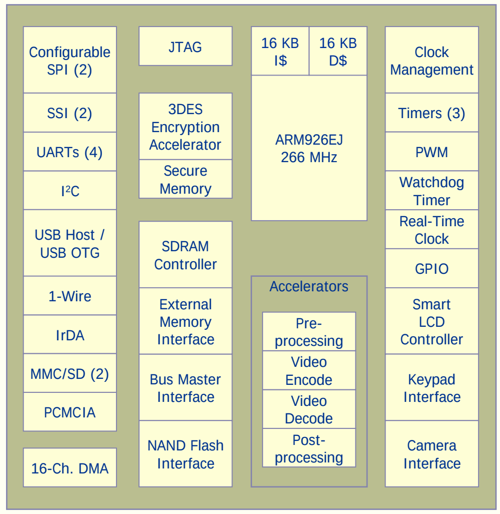
- ⬆ Performance, efficiency on video applications vs. general-purpose processors
- ⬇ But not as strong as customized solutions, and may not be adequate for demanding tasks
- ⬆ Media-oriented development tools, infrastructure
- ⬇ Tools not as sophisticated as those available for general-purpose processors
  - ⬇ Often, poor compiler quality
- ⬆ Stable, mature technology and vendors
- ⬆ Third-party audio/video application software available
  - ⬇ Support for non-DSP software not as strong as, e.g., GPPs
- ⬆ Relatively low development cost, risk

 20

Example Application Processor

Freescale i.MX21

- Based on a 266 MHz ARM9E
- Accelerators for MPEG-4 and H.263 encode and decode, video pre-/post-processing
- Strong emphasis on energy-saving design
  - Accelerators
  - Active well biasing
- BDTIsimMark2000 score: 550
- MPEG-4 decode (CIF @ 30 fps): ~5 MHz
- Good development tools, optimized DSP software available, good OS options
- Price $17, qty 10k



 21

Application Processors

Strengths and Weaknesses

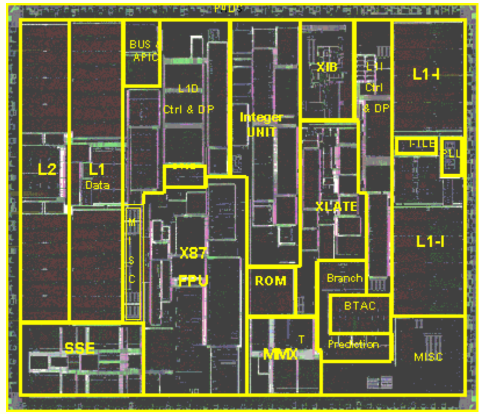
- ⇨ Adequate performance for portable video
  - ⬇ Typically less powerful than other types of processors
- ⬆ Emphasis on energy efficiency
- ⇨ Programming model may be simple or complex
- ⬆ 32-bit GPP core is a good target for non-media tasks
  - ⬆ E.g., TCP/IP network stacks
- ⇨ Good tools, but generally weak on support for video application development
- ⬆ Very good third-party OS, software component support
- ⬆ Compatibility good for ARM core
  - ⬇ But generally use proprietary video processing hardware
- ⬆ High integration

 22

Example PC CPU

VIA Technologies C3

- 1 GHz x86 compatible
- Moderate power consumption, cost
- SSE support for video applications, supports fixed-, floating-point types
- Access to massive x86 3rd-party software, tools base
- Familiar to software, hardware developers
- MPEG-4 decode (D1, 30 fps) using 35% of CPU, when using VIA CN400 chipset
- CPU: $70, chipset: $23 (qty 10k)



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 23

PC CPUs (GPPs)

Strengths and Weaknesses

- ⬆ Can handle complex video processing tasks
  - ⬆ May be as fast or faster than DSPs...
  - ⬇ ... but cost & power consumption typically higher
- ⬇ Dynamic features complicate optimization, real-time design
- ⬇ Generally weak on integration
- ⬆ Many options for OS, 3rd party application software
- ⬆ Easier migration of PC applications
- ⬆ Excellent targets for non-signal-processing tasks
  - ⬆ E.g., protocol stacks
- ⬆ Compatibility, multi-vendor architectures common
- ⬆ Development tools mature, powerful
  - ⬇ But typically lack features useful for video application development

 24

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 25

Processor Selection Methodology

Use a hierarchical approach to make the problem manageable:

- Determine selection criteria
- Prioritize or assign weights to selection criteria
- Use critical criteria to eliminate obviously unsuitable choices
  - Begin with classes of processors
- Evaluate and rank candidates
- Weigh trade-offs among non-critical criteria
- Iterate as necessary
  - Refine criteria and analysis of candidates

 26

Processor Selection Criteria

Signal-Processing-Centric Concerns

- Performance on relevant audio/video tasks
  - Speed
  - Memory bandwidth: on-chip, off-chip
  - Energy consumption
  - Execution-time predictability
    - Dynamic features confound optimization
  - Data word size(s)
- Memory usage

 27

Processor Selection Criteria

Signal-Processing-Centric Concerns

- On-chip integration
  - Memory, peripherals, I/O interfaces, coprocessors
- Development effort, risk
  - Media-oriented tools, infrastructure
  - Programming model complexity
  - Application software components
  - Reference designs
  - Tools, support (vendor, 3rd party)
    - Accurate cycle-count and memory profiling
    - Visibility into cache, pipeline
  - Features useful for integration, real-time testing
    - E.g., on-chip debug support

 28

Processor Selection Criteria

General Concerns

- Cost
- Packaging options
- Roadmap
  - Availability; reliability of supply
    - Multi-vendor architectures a plus
  - New spins, new architectures, compatibility
  - Core version available?
- Special requirements
  - Variable-voltage operation

 29

Development Considerations

- Language support
  - Quality of C compiler; availability of C++ compiler
  - Support for assembly language optimization
- Software availability
  - Video processing components
  - Player, device drivers, operating system
- Hardware/software reference designs
- Debug/development benefit from tools with:
  - Peripheral and multi-processor simulation
  - Non-intrusive, real-time debug
- Compatibility, developer familiarity

 30

Availability and Roadmap

- Risk
  - Is the chip available in volume today?
  - Are there second sources of the chip or compatible chips?
  - What does the errata list look like?
- Roadmap
  - What is the vendor's commitment to evolving the chip? E.g., improved integration, reduce cost
  - What is the vendor's roadmap for next-generation chips? Compatibility?
  - What is your confidence that the vendor will execute on its roadmap?

 31

Benchmarking Approaches

Applications	Portable video player	Set-top box	Video conf. system	…		
Application Components	OS	Audio decoder	Audio encoder	Speech codec	Video decoder	Video encoder
Algorithm Kernels	FIR	FFT	DCT	VECADD	…	
Operations	Add	Mult/MAC	Shift	Load	…	

 32

What's Wrong with MMACS?

MMACS approximates performance on some signal processing algorithms like FIR filters, but:

- It ignores other operations required to sustain repeated MACs
- It ignores memory bandwidth bottlenecks
- Many important signal processing algorithms don't use MACs!

Example: 'C5510 and PXA255

- 200 MHz 'C5510: 400 MMACS and 1,200 million bytes/sec
- 400 MHz PXA255: 800 MMACS and 1,600 million bytes/sec
- These two processors have comparable signal processing speed!

 33

Algorithm Kernels

- Computationally intensive portions of signal processing applications
  - FFTs, filters, bit unpack, ...

↑ Strong predictors of performance

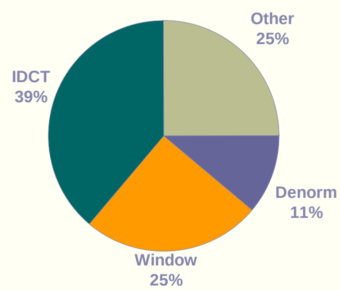
  ↓ Do not measure system-level performance or OS overhead

↑ Modest programming effort

↑ Results for common kernels widely available

↓ Difficult to apply to multi-core processors, hardware accelerators, FPGAs, etc.

- Examples: BDTI Benchmarks™, BDTI Video Kernels™



 34

Application Components

Model a key signal processing task
- ↑ Often representative of overall workload
- ↑ Easier to implement than a full application
- ↓ Less general than a set of kernel benchmarks

Larger workload vs. kernel benchmarks
- ↑ Allows comparison of different types of architectures
- ↑ Simplifies programming rules

Can benchmark the entire system
- Capture effects of memory size, bandwidth, etc.
- ↓ Does not capture effects of combining multiple tasks

Example: BDTI Video Benchmarks™

 35

Full Application Benchmarks

- ↑ Potential for highly accurate results
  - ↓ Results useful only for specific application (or highly similar applications)
  - ↓ Applications tend to be ill-defined
- ↑ May be able to use existing application code as a benchmark ...
  - Example: BDTI Solution Certification service
- ↓ ... but costly and time-consuming to implement a new application
- ↓ For processors, similar results via simpler approaches
  - But this is not true for all implementation technologies

 36

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Conclusions

- Choosing a processor for a consumer video product is easy
- Choosing the *best* processor for your particular product is hard
  - Vast range of options
  - Many complex, competing criteria to consider
  - Poor information
  - Fast changing requirements and options
  - Limited time and resources

Conclusions, cont.

- Use a hierarchical approach
  - Develop a well-defined hierarchy of product requirements
  - Start with the critical criteria and iteratively narrow the field
  - Expect to make trade-offs
- Assessing performance is a challenge
  - Resource-hungry algorithms, cost-constrained processors, many variables
- Development-related considerations are key
- Appropriate integration is essential to low system cost

 39

Trends: Processors

- Consumer video applications are becoming a major focus of processor vendors
  - Expect more competitors, more options
- Technology, competition pushes performance up; price and power consumption down
  - Enabling new types of products, new levels of functionality
  - But not all processors are well matched to video processing workloads
- Increasing architectural complexity
  - Many heterogeneous multiprocessors
- Integration increasing
- Development infrastructure is a key differentiator

 40

Trends: Development

- Systems are becoming more complex
- Processors are becoming more complex
- Algorithms are becoming more demanding
- Optimization continues to be essential
- Huge processor-to-processor differences in development infrastructure
  - Support for video applications
  - Off-the-shelf, optimized software components increasingly important

For More Information…
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Inside [DSP] newsletter and quarterly reports

Benchmark scores for dozens of processors

Pocket Guide to Processors for DSP

- Basic stats on over 40 processors

Articles, white papers, and presentation slides

- Processor architectures and performance
- Signal processing applications
- Signal processing software optimization

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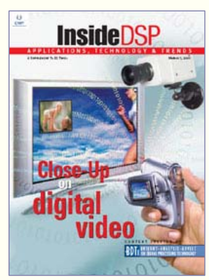

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