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# Power Up: Moving Toward Parallel Processing in Medical Imaging Compute Systems

An Overview of Hardware Trends and Opportunities

## Overview

The market landscape for today's computed tomography (CT) imaging devices is complex, and the competition fierce among medical equipment providers striving to be first to market with solutions that deliver breakthrough diagnostic imaging quality and rendering speed. However, designing state-of-the-art CT imaging systems entails deciphering an exceptionally complex interaction of software and hardware. In these systems, mathematical theory intersects with advanced compute technology; numerous advanced technologies work together to deliver ever-increasing performance levels.

Every year, new innovations in hardware and software emerge that can potentially enable significant performance gains. Choosing between serious contenders is a major task, since various imaging modalities span large performance ranges and the market is extremely competitive on all fronts.

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## Parallel Processing: The Edge of the Next Frontier

Recent advances in *parallel processing* show great promise in enabling improvements in CT equipment performance. Parallel processing, specifically parallel computing, is a form of computation in which many calculations are carried out simultaneously. The concept operates on the principle that large problems can often be divided into smaller ones, which are then solved concurrently. Parallelism has been employed for many years, mainly in high-performance computing (i.e., supercomputers such as Cray, and PC-based cluster and grid computing), but the more recent rise of multicore processor technology such as Intel® Quad-Core technology, which delivers four complete execution cores within a single processor, has brought the power of parallel processing down to the server and subsystem level.

This white paper explores some of the various options available to system designers to effect parallel processing, and available high-performance compute systems from Radisys that can enable them to do so.

## Processor Dynamics: Core Enabling Technology for Today's CT

The higher X-ray detector resolutions and faster data acquisition times available in an advanced CT gantry, coupled with modern high-performance compute hardware, enable remarkable diagnostic capabilities. Today's CT spatial resolutions are sub-millimeter; images that took hours to process 10 years ago can be executed in seconds on contemporary compute platforms.

Like many technologies, some fundamental CT theories were developed decades ago, but have been impractical to implement until the availability of recent advances in parallel processing. For example, there are several well-known methods used in CT; these range from the brute force of various back-projection techniques, to more mathematically elegant algebraic approaches based on solving matrices. In general, these and all CT methods can benefit from the faster data processing that parallel processing affords.

*High-performance graphics subsystems are enabling dramatic performance improvements in medical imaging equipment.*

### Processor Options Enable Endless Solution Permutations

The compute options for "crunching the numbers" are almost as diverse as the available numeric methods. In the CT space, an array of niche hardware solutions has evolved. Some algorithms naturally apply well to certain processor designs and have been heavily optimized to specific microarchitectures, to maximize performance. Other approaches have started with fairly generic image processing libraries and applied massive parallelism to reach the desired performance level.

Specifically, some of the more common processor types found in modern CT systems include:

- Intel® architecture CPUs such as Multi-Core Intel® Xeon® Processor
- General Purpose Graphics Processing Units (GPGPUs) derived from graphics processors such as Nvidia and ATI (AMD) GPUs
- Field programmable gate arrays (FPGAs)
- Digital signal processors (DSPs)
- Application-specific integrated circuits (ASICs)

There are many tradeoffs in the system architecture of these compute platforms. Matching specific data flow parameters to available processing hardware is an ongoing effort and the subject of much research in industry and academia alike.

## Heterogeneous Compute Platforms are the Wave of the Future in CT

In the CT world, these processors have various strengths and weaknesses. The newest design trend is to create systems that combine several of these options, each executing its piece of the algorithm more optimally than any single, homogeneous solution processing the algorithm in its entirety. Called *heterogeneous compute platforms*, these new systems are typically CPU-based, accessing a set of coprocessors to offload certain calculations.

In heterogeneous compute platforms, the compute topology can vary drastically based on the application. Higher end CT systems typically comprise server grade CPU clusters (ranging in size from one to many multi-core CPUs) linked via PC Express high-speed serial I/O (PCIe) to fast, commercial-grade available GPGPUs.

On the lower end, a cart-sized, portable ultrasound system might match a single desktop-grade CPU with a consumer-grade graphics processor (GPU), a cost-efficient solution that is appropriate for the less compute-intensive applications found in ultrasound and other imaging modalities.

## Standards are Driving Parallel Processing

Regardless of the mix, parallel processing at one or more levels is the general trend in imaging systems. This is being fueled in part by the rise of OpenMP, an application programming interface (API) for multi-platform shared-memory parallel programming in C/C++ and Fortran. OpenMP is a portable, scalable model that gives shared-memory parallel programmers a simple and flexible interface for developing parallel applications for platforms ranging from the desktop to the supercomputer.

Figure 1 shows the impact of using OpenMP with a 3D CT reconstruction algorithm and applying multiple CPU threads. In this example, a simple application of OpenMP yields approximately a 10x increase in processing speed over a single core when running on eight physical/16 logical cores. This is a significant acceleration that can be achieved using one of the simplest parallelization methods available.

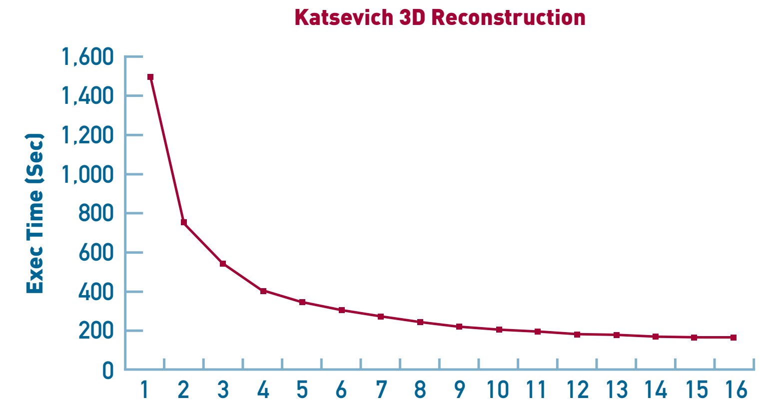


**Figure 1.** *Parallel implementation of Katsevich algorithm for 3D CT reconstruction on a two-socket x86-based server with Quad Core, Symmetric Multi Threading (SMT) enabled CPUs. Source code courtesy of Eric Fontaine and Dr. Hsien-Hsin S. Lee, Georgia Institute of Technology.*

## Hardware Trends in CT: Faster, with More Storage

In CT reconstruction, the trend is toward larger detectors and more scan, which results in more data to process. To keep processing times from becoming prohibitively long, the algorithms are being parallelized among a growing number of processor cores. The core count can easily approach 1,000 in an advanced CT machine, typically composed of a mixture of coprocessor PCIe cards working in tandem with a small cluster of server-class CPU multi-core processors. The actual algorithm employed will dictate the ideal balance of CPU cores to GPU cores.

Often the initial data capture streams into the system faster than it can be processed in real-time, so the data has to be pre-buffered. This is usually done using a RAID storage system. Once enough data is available, computation begins. Many choices are available for this part of the model, from custom, highly proprietary hardware-specific paradigms to open source, “brute force,” hardware-based abstraction methods.

As algorithmic density increases (math operations per data element relative to memory transfers required to bring the data into the processor), the round-trip cost of a memory transaction from host, to and from a coprocessor, then back to host is better amortized, making the data pre-buffering model efficient enough.

But if, for example, each pixel only gets operated on once per memory transaction, then the round-trip memory transfer can be too expensive in terms of total compute time. Modern CT reconstruction algorithms have numerous steps, involving back-projection, filtering, Fast Fourier Transforms (FFTs), interpolation, convolution, noise subtraction, segmentation and other techniques. Each of these subroutines can deliver dramatically different performance when executing on different processor technologies.

## Doing the Math: Optimizing for Image Processing

A CT compute system must balance the power, thermal and acoustic requirements of the product it is integrated with. The ratio of CPU core to coprocessor core count is critical and algorithm dependent, but there are many trade-offs to consider when designing the overall hardware architecture of the system. These variables include:

### *Processor Mixture and Count*

- *Memory*
  Internal L1, L2, L3 CPU cache sizes
  External (system) size, number of channels, rank, technology, speed, bus
  Coprocessor board external/global size
- *Bus*
  PCI Express 1.0, 2.0
  Number and size of PCIe slots relative to CPU countPCI-X for legacy I/O boards
- *System High Speed Interconnect*
  Gigabit Ethernet
  Infiniband
- *Storage*
  RAID
  Solid state for mobile/low power applications

## The Growing Importance of Open Standards and Outsourcing

With each new processor technology, it is more difficult for individual developers and teams to keep abreast, let alone master, an ever-growing set of associated software tools (compilers, debuggers, libraries, instruction sets, etc.) Abstraction tools are being offered to simplify the growing programming challenge.

Open source initiatives such as OpenMP offer tools to parallelize algorithms across CPUs, analogous to the parallelization found in high performance computing (HPC). As the line blurs between HPC and high-end medical imaging, a growing number of commercial offerings are appearing (e.g. RapidMind, etc. ) that fill the need for abstraction of multi-core parallel compute details.

In addition, complete medical imaging software libraries, both generic and optimized for specific processing hardware, are being made available. In the past, medical imaging equipment makers were forced to invest heavily in custom hardware and software primarily because they had no other option; today, other choices are emerging. Large medical imaging system providers are seeing value in outsourcing more and more of the compute platform design, which allows them to focus more closely on their core competencies such as:

- System mechanicals
- X-ray source and detector technology
- High-level algorithms

Parallel processing requires a strong understanding of the data flow and interdependencies, and the micro-architecture involved. This is an expensive, non-core skill set for imaging system providers to maintain across numerous products and technologies.

# Radisys: Imaging Subsystems Engineered for Performance and Stability

In summary, the options and approaches for medical imaging processing are vast and ever-changing. As a result, the cost-benefit analysis of compute architecture is expensive, complicated and requires significant expertise. Deciding which compute models to consider can be daunting, and exploring those choices more deeply immediately exposes many variables to consider.

Radisys is committed to advancing imaging technology through the investigation and development of compute platforms and products that are optimized for today's medical imaging challenges. Radisys Procelerant™

embedded servers provide industry-leading compute power for high-performance imaging applications. These Radisys imaging subsystems deliver advanced parallel processing capabilities to accelerate diagnostic processes and improve departmental efficiency. Radisys's core offerings comprise:

- *Procelerant RMS420-5000XSL:* This quad-core 4U embedded server combines very high compute performance with dual PCI-Express (PCIe) x16 slots (x8 electrical) for high performance graphics and/or co-processor cards. It features:
  - Compact 4U x 20" x 19" chassis
  - 2 X Quad-Core Intel® Xeon® Processor
  - Intel 5000X Chipset
  - Up to 32 GB DDR2-667 FB-DIMM memory
  - Two PCIe x16 slots (x8 electrical)
- *Procelerant RMS420-Q35JD:* This 4U embedded server is available with a single dual or quad-core processor to deliver high performance at an attractive price. This server is ideally suited for medium performance imaging and signal processing applications. Features include:
  - Compact 4U x 20" x 19" chassis
  - Intel® Core™ 2 Quad or Intel® Core™ 2 Duo Processors
  - PCI-Express 16, x4 and x1 slots + 4 PCI slots
  - Dual channel memory, up to 8 GB DDR2 667/800
  - Supports dual displays and high definition Audio

Procelerant solution highlights include:

- *Optimized High Performance:* Procelerant servers incorporate high-performance Intel® processors, advanced video cards and graphics coprocessors. Our systems are built on industry standards but can be optimized to meet customer's specific application needs, leveraging Radisys's embedded systems design expertise.
- *Smaller Footprint/Form Factor:* Radisys Procelerant servers are only 20 inches deep, versus other providers' typical 26 or 30 inches, allowing for a smaller application form factor—a critical benefit in space-constrained healthcare environments.

*RMS420 Embedded Server*

*MRI*

- *Quiet Operation:* Radisys encases high levels of processing power with in specially designed, noise-reducing chassis, allowing medical equipment manufacturers to build devices that can operate safely and quietly in close proximity to technicians and patients.
- *Long Life:* Given long regulatory approval cycles and equipment manufacturers' product lifecycles, Radisys understands the importance of design stability. We work closely with our customers to help ensure the long-term availability of key components and thus avoid costly end-of-life design adjustments, testing and unnecessary regulatory approvals.

Choosing solutions from Radisys allows medical imaging equipment providers to focus engineering resources on developing value-added differentiation. The design organization can maximize its impact with breakthroughs in core competencies, not fundamental functionality.

### Let Radisys Help You Move Your Business Forward

Radisys uniquely offers the engineering expertise that can directly translate into a sustainable competitive advantage for medical device manufacturers. Radisys devotes significant resources to the cost-benefit analysis of new technologies and designs, and works closely with our customers to develop optimal solutions for specific applications.

These capabilities, combined with our commitment to advancing the industry's reach into both established and emerging markets, makes Radisys a partner you can depend on to improve your business today, and move it forward into the future.

For more information on how Radisys medical imaging solutions can help you bring high-performance solutions to market quickly, please visit www.radisys.com/medical.

## About Radisys

Radisys (Nasdaq: RSYS) is a leading provider of advanced solutions for the communications networking and commercial systems markets. Through intimate customer collaboration and combining innovative technologies and industry leading architecture, Radisys helps OEMs, systems integrators and solution providers bring better products to market faster and more economically. Radisys products include embedded boards, application enabling platforms and turn-key systems, which are used in today's complex computing, processing and network intensive applications.

For more information, visit http://www.radisys.com, write to info@radisys.com, or call 800-950-0044 or 503-615-1100.

## About the author

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Mike Hinds is a technologist and system architect in the CTO office of Radisys Corporation, with a dual focus on the hardware and software aspects of medical imaging systems. Mike helps Radisys to define, and provide to the medical imaging industry, high performance, heterogeneous compute systems that combine CPUs with accelerating coprocessors. He holds a Ph.D. in Space Plasma Physics and started his career at the Space Telescope Science Institute (Hubble) writing software for imaging systems.

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