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White Paper

Brilliance 64-channel
3D, abdomen, abdome
Body, brain, Brilliance
Cardiac, chest, chest C
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image quality, iterative
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Recontruction, reconstr
retrospective, routine c
Vascular, workflow

Accelerating CT reconstruction

White Paper
Philips CT Marketing • Philips Healthcare

Executive summary

Computed tomography (CT) reconstruction is computationally demanding, but by applying the latest high-performance processors and advanced software programming techniques, it's possible to reign in processing times. With the resulting performance gains, CT scanners operate faster while also enhancing image quality and increasing acquisition flexibility. These advances in CT imaging enable radiologists and department managers to improve patient care, reduce the time to diagnosis and boost the department's productivity.

As CT continues to evolve, some of the traditional workflow bottlenecks, such as acquiring data, have disappeared, only to be replaced by new bottlenecks. For example, image reconstruction time is constraining CT productivity at many institutions. Today, a patient remains on the table while the department staff verifies the acquisition coverage, confirms the contrast uptake in CT Angiography (CTA) procedures and determines whether the radiologist needs a delay phase for diagnosis. For these reasons and others, reconstruction time is tying up the CT department.

Philips RapidView* reconstruction technology relieves some of the bottlenecks, significantly reducing reconstruction time and delivering world-class performance to the medical field. Using this technology, the Philips Brilliance* CT 64-channels scanner completely reconstructs 74 percent of its factory protocols in less than 60 seconds. This high level of performance is attributable to RapidView's algorithm enhancements, which are optimized to run on Intel® Xeon® processors with quad-core technology.

This paper quantifies the RapidView reconstruction system performance improvements by presenting CT total reconstruction time data - before and after - for different protocols. The image reconstruction speedup is explained from the standpoint of software algorithm and hardware advancements. The paper describes how Philips CT solutions can help increase departmental productivity and improve clinical care by accelerating image reconstruction performance.

Dissecting reconstruction time

The time required to complete a CT study, called the total reconstruction time, can be broken down into two components, as shown in Figure 1. The first portion is called the time to first image (TTFI), and it is the time (t2 - t1) required to acquire and reconstruct the first image. In an emergency situation, TTFI is critical because it dictates when a clinician can begin assessing a patent's condition.

Before the first image can be processed, the reconstruction processor in the CT scanner must wait until there is enough data available to begin reconstruction. This delay is a byproduct of helical scanning, a process that doesn't instantaneously acquire all of the data needed to reconstruct an image. The helical motion may actually delay reconstruction until multiple rotations have been completed. The advent of 3D reconstruction, used for multislice CT, exacerbates this problem.

After the first image has been reconstructed, the time to the remaining images (TTRI) comprises the remainder of the reconstruction time, (t3 - t2) in Figure 1. The number of remaining images depends on several factors, including the procedure type and scan length.

The relative time contribution of TTFI and TTRI for various protocols is shown in Figure 2, represented as a percentage of the total reconstruction time (TTFI + TTRI). The average TTFI (first image) contribution for these helical factory protocols is 19 percent of the total reconstruction time. Overall, the range of TTFI contribution is quite wide; 10 to 31 percent for abdomen and standard pediatric protocols, respectively.

TTFI encompasses a larger percentage of the overall reconstruction performance of a system when the scan length decreases. In the case of pediatric and head protocols, the scan lengths are inherently shorter (e.g., fewer images) than the other procedure types, hence the TTFI contributions to the total reconstruction time are relatively large, 31 and 29 percent, respectively.

These results indicate that basing reconstruction performance on images per second alone is not sufficient, because TTFI could be considerably larger than the average image reconstruction time. In scenarios where obtaining an image quickly is critical, TTFI data is more relevant than images per second. The total reconstruction time can have a significant impact on clinical throughput and patient waiting time.

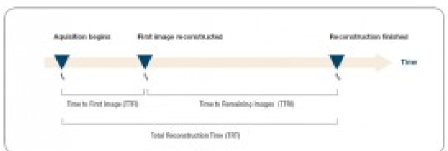


Figure 1
Components of total reconstruction time

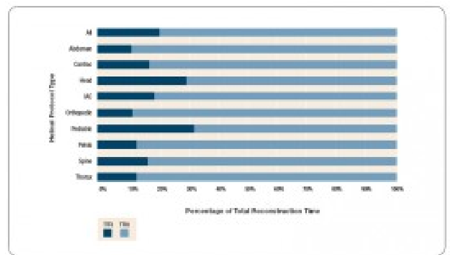


Figure 2
Total reconstruction time breakdown

Maximizing Image Reconstruction Performance

Image reconstruction performance is largely dependent on the performance of both hardware (Intel® Xeon® processors) and software (Philips RapidView reconstruction algorithms). Following is a discussion of how each of these two technology streams combines to continually improve overall reconstruction performance, as well as some of the tradeoffs Philips made in achieving the new levels of performance in Brilliance CT scanners.

Tracking Moore's Law
Moore's Law evolved from an observation made by Gordon Moore, Intel Corporation co-founder, that the number of transistors in integrated circuits (e.g., CPUs) appeared to be doubling every 18 months with no increase in cost. Intel innovation has managed to keep processor technology on this track for 30 years, which produces a dramatic increase in transistor count and boosts processor performance. Since CT reconstruction software algorithms are computationally very heavy, there is a significant speedup when they run on higher performance processors. The faster the processors in the reconstruction server, the faster the reconstruction is completed.

Through 2005, processor performance gains were obtained through incremental frequency changes that resulted in relatively small increases in reconstruction performance, as shown in Figure 3. With the addition of more processing cores in 2006, processor performance jumped, and reconstruction algorithms, which are highly parallel, ran much faster on the new multi-core processors. This period marked the advent of the multi-core processor era, which was ushered in by the first Intel Xeon processor with dual-core technology based on the Intel® CoreT microarchitecture. This meant there were two processor cores, not one, in the same footprint.

RapidView performance increased linearly with the number of cores, which occurred without changing the processor count in the server. Intel Xeon processors with quad-core technology followed in 2007, and dual processor servers, equipped with two quadcore processors (8 cores), became available in 2008. This server configuration has four times more processing cores than the RapidView server of 2005. Commensurately, RapidView performance is approximately four times what it was in 2005 for a given server configuration. The net result from this performance gain is that Philips can reduce the number of servers, from three to one, while holding performance constant.

The hardware foundation for RapidView reconstruction technology adopted various Intel® processor technologies, shown as three generations in Figure 4. Philips' ongoing commitment to use the latest

Intel processor technology makes it simple to upgrade the existing installed base, and this helps Philips maintain its leadership position in the industry.

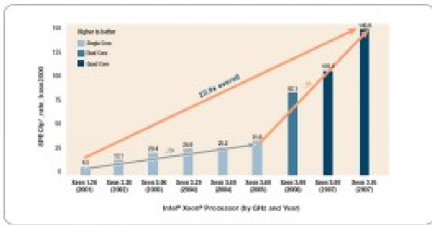


Figure 3
Timeline of floating point performance (Refer to configuration details in Appendix)

Figure 4
Philip's adoption of Intel® processors

Selecting Reconstruction Algorithms
The underlying algorithms for reconstructing images from RAW data are complex and computationally demanding. And with the continuing advances in wide-area coverage, reconstruction algorithms are consuming even more computing power. Thus, in the field of reconstruction algorithm development, there are always tradeoffs to be made when choosing algorithm techniques. CT scanner developers must select algorithm techniques that don't exceed their computing budget, which means making performance decisions, such as choosing between final image quality and total reconstruction time.

The filtered back projection method is widely used by image reconstruction algorithms in the CT industry. It involves a number of inherent assumptions, which reduce the complexity of the reconstruction process and enable the production of high-quality images within a reasonable amount of time. Other algorithms theoretically produce better image quality than the ubiquitous filtered back projection method, but their use involves some compromises. For example, full iterative reconstruction is fundamentally insensitive to noise and has the capability to reconstruct an optimal image from incomplete data. However, the CT industry has not adopted these alternative algorithms because they are so computationally challenging - image reconstruction would take seconds or minutes, as opposed to a fraction of a second. Using these algorithms could mean waiting hours, or even days, for a study to be reconstructed. This is completely impractical since the data acquisition process only takes seconds, but given the past evolution of the reconstruction technology, the use of these techniques may be realized in the near future.

Using Processing Power
As image reconstruction and processor technologies evolve, new opportunities arise, and the challenge is to appropriate processing power in a way that produces the greatest benefit. Developers must carefully consider the balance between improving total reconstruction time and performing more complex reconstruction techniques that enhance image quality. This careful design balance can easily be seen in the latest generation of Philips RapidView technology. Philips has taken advantage of the latest processor technology and optimized reconstruction algorithms to deliver higher performance and better image quality. As a result, the new generation of RapidView performs reconstruction much faster than prior-generation technology, as shown in Table 1. The speedup ranges from up to 60 percent for brain spiral to 14 percent for cardiac retrospective spiral.

Table 1. Reconstruction Time Improvements

Protocol	Improvement in total reconstruction time versus prior technology[1]
Routine abdomen	Up to 29%
Cardiac retrospective spiral (one phase)	Up to 14%
Brain spiral	Up to 60%
Brain axial	Up to 55%
Routine chest, abdomen, pelvis	Up to 28%
Routine chest	Up to 39%
Median of all factory protocols	Up to 37%

Realizing Clinical Benefits

Advances in CT imaging are yielding significant clinical benefits, such as higher system productivity, better image quality, more acquisition flexibility and shorter time to diagnosis.

Higher System Productivity

The latest generation of RapidView reconstruction comprises many enhancements that enable the Brilliance CT 64-channel scanner to deliver more value to clinics. Scanner productivity is higher because RapidView reconstruction times have been reduced by increasing processing power and optimizing reconstruction algorithms. These improvements enable 74 percent of the factory protocols to be completely reconstructed in less than 60 seconds. The median total reconstruction time of the factory protocols has decreased 37 percent since the introduction of the Brilliance CT 64-channel scanner (generation 1), as shown in Figure 5.

A reduction in total reconstruction time increases CT scanner productivity and enables faster acquisition verification, which allows the technologist to spend more time with the patient. Technologists must verify the acquisition covered all of the intended anatomy and captured the proper contrast enhancement for CTA studies. Additionally, they need to check whether the patient requires a delay phase to assist in ruling out specific diseases.

Faster image reconstruction can also shorten exam times, which quickly reduces backlog and frees up capacity for additional procedure volumes in the department. Using the latest generation of reconstruction technology, radiologists can make clinical determinations more quickly.

Figure 6 demonstrates the significant total reconstruction time reduction with the introduction of the third generation of Philips RapidView reconstruction technologies. The total reconstruction time for head protocols, on average, is 48 percent less than first-generation technology, and the average time for all protocols is 26 percent lower (lower is better). The percentages indicate the relative performance compared to Generation 1 described in Figure 4. When Generation 1 is compared to itself, the performance difference is obviously zero; hence the figure shows 0%.

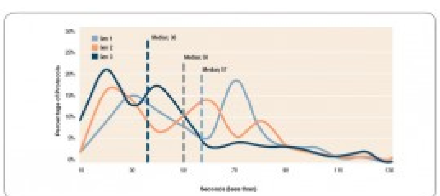


Figure 5
Total Reconstruction Time for Three Scanner Generations

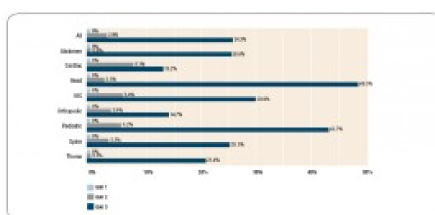


Figure 6
Total Reconstruction Time Improvements Over Three Scanner Generations

Enhanced Image Quality

Image quality is a function of many components. These components can be grouped into three different themes: patient, system user and CT system technology.

Voluntary patient compliance (patient movement, breath-hold compliance, etc.) and involuntary patient compliance (heart rate, arrhythmias, etc.) and the size of the patient all affect image quality. The system user can take action to control image quality, such as:

- Coach the patient properly
- Select the appropriate protocol
- Ensure the correct parameter selection matches the patient's physiology
- Match the injection protocol with the patient's physiology and the selected protocol
- Center the patient properly

The CT system technology impacts image quality, and at a sub-system level this means X-ray tube, detector and reconstruction technologies. All three of these pieces of technology must function in unison in order to deliver high-quality images.

In summary, achieving the optimal image is a complex task involving different components and their diverse aspects. Philips offers various options to optimize these components, but the following discussion is focused on CT scanner reconstruction technology.

The hardware performance gains of the new RapidView reconstruction platform are sizeable enough to make CT system developers consider how to use the additional processing power: produce higher quality images, reduce the total reconstruction time or both. This is an important design decision, which is made for each procedure type after a careful analysis of the demands of today's clinical environment. Such a review process identifies different ways to put the new found processing power to work. The outcome is that some procedure types are optimized to improve image quality, and others benefit from reduced total reconstruction time while maintaining existing image quality standards.

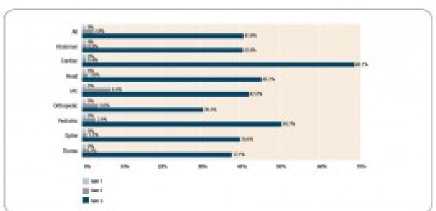


Figure 7
Time to first image improvements (TTFI) over three scanner generations

New Acquisition Flexibility
Intel Xeon processors with quad-core technology speed up RapidView reconstruction, which provides additional flexibility to radiologists and department managers when they establish the departmental standard for quality of care. For example, acquisition parameters, such as pitch, have a significant impact on the resultant total reconstruction time. The challenge is to determine the ideal combination of acquisition parameters that optimizes image quality without requiring a prohibitively long reconstruction time. Making the decision easier, the RapidView reconstruction performance improvements enable CT professionals to optimize acquisition protocols for image quality with no reconstruction time penalties. Post optimization, CT departments may even experience reduced overall total reconstruction time due to the high computing performance of Intel Xeon processors with quad-core technology.

With the faster image reconstruction, radiologists can request additional reconstructions, using different filters such as bone and soft tissue filters, without negatively impacting the scanning operation. While this produces more data to interpret, it can simplify the reading process and increase radiologists' productivity, as each set of data is tailored specifically for their current interpretation need. Tailored data sets can also improve the quality of care as radiologist are always reviewing patient data in its ideal form, reducing the likelihood of missing a critical piece of information.

Shorter Time to Diagnosis
In trauma situations, clinicians need information as fast as possible to be able to quickly administer

treatment. By reducing reconstruction time and the time to diagnosis, RapidView enhances the clinic's workflow. Clinicians can access the images faster, which speeds up diagnosis and ultimately patient treatment. Faster reconstruction also enables quicker verification of a successful acquisition and allows the patient to be moved to the next stage of the trauma treatment procedure.

Since images are reconstructed individually, the time to first image (TTFI) can be critical in emergency situations, because clinicians can begin interpreting results before the entire study is reconstructed. In trauma situations, where seconds count, getting the first image in the clinician's hands can go a long way towards saving lives. The newest version of RapidView reconstruction enables significant improvements in TTFI over previous generations of RapidView reconstruction, as shown in Figure 7. The TTFI for cardiac protocols is an incredible 68 percent less than first-generation RapidView technology, and the average time for all factory protocols is 43 percent lower (lower is better). As in Figure 6, the percentages indicate the relative performance compared to Generation 1 (see Figure 4). These improvements indicate that physicians can start making their diagnoses earlier, leading to better outcomes for patients who are in time-critical situations.

Accelerating CT Reconstruction

Philips has made significant improvement to its RapidView reconstruction unit for the Brilliance CT 64-channel scanner, as shown in Table 2.

Table 2. Highlights of Phillips CT Reconstruction Improvements

74% of the routine protocols will be reconstructed in less than 60 seconds
37% improvement in the median reconstruction time for routine protocols
43% improvement in TTFI for routine protocols
68% improvement in TTFIs for routine cardiac protocols

Increasing Departmental Productivity

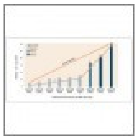
Accelerating CT reconstruction time helps improve patient care, increase department productivity, enhance image quality, provide additional acquisition flexibility and decrease the time to diagnosis. To speed up medical image processing, Philips adopts the latest Intel processors because they deliver the computing horsepower required by today's and tomorrow's demanding image processing algorithms. Philips has a well-established commitment to practical, affordable technology migration, making sure all customers have easy access to the innovation needed for continuous improvements to departmental productivity and clinical care.

Appendix

Configuration details for SPECfp*_rate_base2000 performance results on Intel® Xeon® Processors

Year	Brand Name	Xeon Freq	Cores/CPU	FSB	Chipset	SPECfp_rate*_base2000	Microarchitecture
2001	Intel Pentium III 1.40 GHz 512M L2	1.26	1	133	SW HE-SL	6.5	Intel Pentium® III
2002	Intel Xeon 3.06 GHz 1M L3	2.20	1	400	E7500	13.1	Intel NetBurst®
2003	Intel Xeon 3.06 GHz 1M L3	3.06	1	533	E7501	20.4	Intel NetBurst®
2004	Intel Xeon 3.60 GHz 1M L2	3.20	1	533	E7501	24.0	Intel NetBurst®
2004	Intel Xeon 3.60 GHz 1M L2	3.60	1	800	E7520	25.2	Intel NetBurst®
2005	64-bit Intel Xeon 3.60 GHz 2M L2	3.60	1	800	E7520	31.6	Intel NetBurst®
2006	Dual-Core Intel Xeon 5160	3.00	2	1333	5000p	82.1	Intel Core®
2007	Quad-Core Intel Xeon X5365	3.00	4	1333	5000p	105	Intel Core®
2007	Quad-Core Intel Xeon E5462	3.00	4	1600	5400	149	Intel Penryn

All the results except the one using Intel Xeon processor E5462 are based on published results at www.spec.org as of January 2009. Intel Xeon processor E5462 result is based on Intel Internal measurement. All results are measured/published in a two processor configuration



This white paper explores how Philips-Intel hardware and algorithmic advances in CT imaging have yielded clinical benefits.

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