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# Rétroprojection 2D sur plateforme SOPC, premiers résultats 2D Backprojection on a SOPC Platform : first results

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**Abstract**— Le développement et la diffusion des équipements TEP passent par la réduction des temps de calcul de la reconstruction des images acquises. Aussi cet article présente une solution mixte logicielle/matérielle pour l'accélération de la reconstruction 2D sur une plateforme SOPC (System On Programmable Chip), la nouvelle génération de circuits reconfigurables. L'architecture présentée permet de résoudre élégamment le verrou posé par la latence des accès mémoire grâce au cache 2D Adaptatif et Prédicatif, tout en proposant un système souple d'utilisation.

## I. INTRODUCTION

As image reconstruction in tomographic modalities is cpu intensive and usually postponed, minimization of examination duration can decrease the cost of PET to make its powerful technology more widely available. The development of new activities such as micro PET, PET mammography, small animal PET impose flexible, simple and fast system.

There are several implementations of back projection on parallel computer, on specific hardware and with hardware-software architecture [5], [6], [3], [2]. The main bottlenecks of such architectures are in one hand the memory accesses to the sinogram and, on the other hand, the modularity and flexibility of those solutions.

In this paper, we present an hardware back projection operator embedded in a SOPC (System on Programmable Chip). The original idea is the way we overcome the memory access bottleneck thanks to a 2D Adaptive and Predictive cache (2D-AP Cache). The operator is controlled thanks to a Power PC processor to get maximum flexibility.

## II. GOALS

### A. The algorithm

The implemented algorithm compute the back projection [1] of the data acquired by the scanner, called the sinogram,  $S$ , which is the Radon Transform of the body with distribution function  $f$ . The sinogram  $S$  is a 2D image matrix of  $K$  columns. Each column  $k$  corresponds to the horthogonal projection of the body on a line of  $r$  detectors horthogonal to the direction  $\theta_k = \frac{k*\pi}{K}$ , from the object  $x$  axis.

### B. The challenge

As the sinogram is kept in a SDRAM like external memory an efficient memory management thanks to a 2D-AP cache [4] overcomes its latency and allow a high level of parallelism. Standard cache based on

a linear access to memory can't be a satisfactory solution because both of their complexity and their weakness to load the needed data. Indeed, memory accesses needed to reconstruct one single pixel  $f^*(x, y)$  follow a sinusoid in the sinogram which is of poor address locality.

## III. ARCHITECTURE

A low cost and efficient strategy is to fit the 2D back projection algorithm on a SOPC (System on Programmable Chip). We choosed to evaluate the architecture thanks to an Avnet developpement board which contains (1) a Xilinx V2Pro with 2 PowerPC processor connected to 1 Million equivalent gate FPGA (2) 32 MBytes SDRAM and 128 MBytes DDR-SDRAM and (3) a PCI interface to a host PC. Thanks to a synchronisation mechanism the sinogram is transferred from the PC to the SDRAM and the reconstructed image from SDRAM to PC.

The 2D back projection system architecture is built around a 64 bits PLB Coreconnect system bus, as illustrated figure 1, and have three main components :

- a PowerPC 405 which manages the global process
- a hardware 2D back projection unit
- the external SDRAM which stores the sinogram

The 2D back projection unit performs the reconstruction of several pixels of  $f^*$  of an arbitrary pattern and downloads the needed data from the

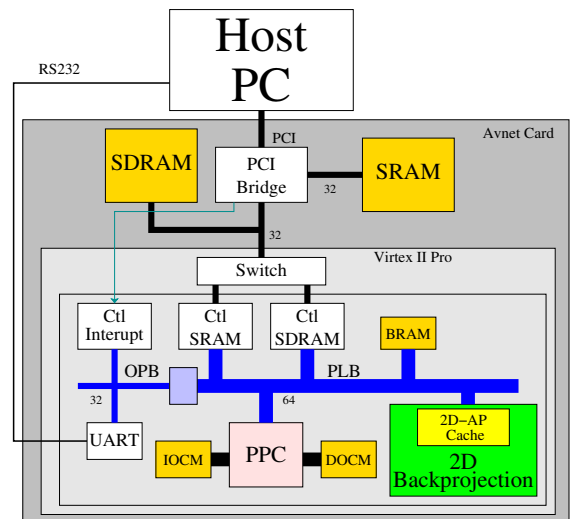


Fig. 1. System architecture

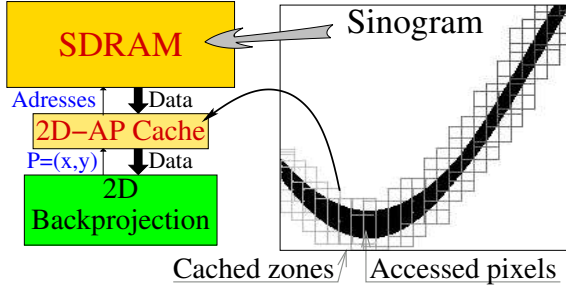


Fig. 2. The 2D-AP Cache concept

SDRAM along the reconstruction process. The 2D-AP Cache module fully exploits the 2D spatial and temporal locality which appears when the processing unit performs the back projection on a set of neighboring pixels. For a square pattern to be reconstructed, 2D locality of the sinogram pixels appears :

- $r$  locality : for a given angle  $\theta_k$ , the  $n^2$  needed pixels are in a segment of maximum length  $\sqrt{2}n$  pixels. A pixel of this segment is used  $\frac{n}{\sqrt{2}}$  times at least.
- $\theta_k$  locality comes from the continuity of the projection operator. If a pixel  $(\theta_k, r)$  has been used then we are likely to use the pixel  $(\theta_{k+1}, r)$ .

As spatial locality increases with  $n$ , the reconstructed bloc size, and, at an extremum, would be the most efficient if the whole sinogram was stored in embedded memory, which is not realistic, we have to found a trade-off between the cache efficiency and available ressources. Indeed, as  $n$  increases the more we need embedded memories to store the intermediate data necessary for the reconstruction process.

The basics of the 2D-AP cache [4] is to copy 2D zones of the sinogram in cache memory to speed-up memory accesses, as shown on figure 2. It aims at predicting which pixels the back projection unit would use by dynamically measuring the mean and pseudo-standard deviation (PSD) of the needed  $S$  pixels.

#### IV. RESULTS

Simulations and measures on the platform show us that we can achieve good reconstruction times thanks to the 2D-AP Cache which reduces the memory overhead to an order of magnitude. The reconstruction time of a  $16 * 16$  square, located at pixel (70,70), for a  $K = 256$  angular resolution is reconstructed in about 100 000 clock cycles instead

Sinogram	Image	Reconstruction Clock Cycles	Time
512*512	320*320	$100 * 10^6$	2 s

TABLE I  
MEASURED RECONSTRUCTION TIMES

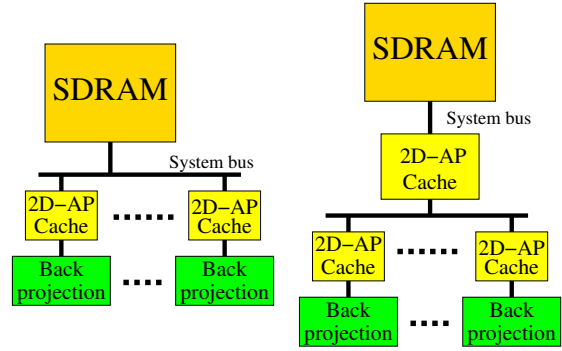


Fig. 3. Shared and hierarchical 2D-AP Cache memory architecture

of  $n * n * K * \text{latency} = 65536 * \text{latency}$  clock cycle and latency  $\approx 30$ .

Full reconstruction times are measured on the VirtexII Pro evaluation platform which runs at 50 MHz and results can be found in table III.

Better reconstruction times can be reached by increasing the computational power and reducing the memory latency. It can be reached by (a) sharing the memory between several operators or (b) designing a hierarchical 2D-AP Cache, such as illustrated figure III.

#### V. CONCLUSION

In this paper, a SOPC based back projection image reconstruction system has been presented. It has been demonstrated that one can achieve high throughput computation despite the bottleneck of memory accesses thanks to the 2D-AP cache.

This a first step to build scalable and flexible reconstruction system and allow more sophisticated algebraic and iterative 2D and 3D reconstruction algorithms for PET imaging. High performances can be reached by parallelizing computations and accessing the database through shared or hierarchical (or both) memory management.

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