Online PET Reconstruction From List-Mode Data

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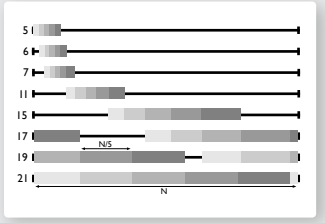
INTRODUCTION

This work proposes an alternative to ordered subsets to improve the convergence speed of list-mode expectation-maximization algorithms.

Instead of subdividing the input data into subsets, the stream of measured coincidence events is processed online and the image is directly updated.

The Sliding Window Expectation-Maximization (SWEM) algorithm is an incremental estimation method that reconstructs explicitly a dynamic image.

STATIC PHANTOM EXPERIMENT

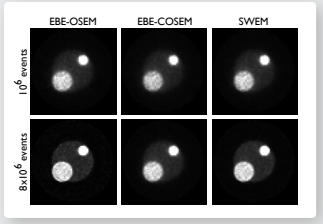


Sliding and Expanding Window

Graphical representation of the pagination-based bookkeeping mechanism of the SWEM algorithm. The number of already processed pages is noted in front of each line. N is the number of events.

- The data stream never ends but loops implicitly (no subset)
- The image is updated incrementally for each new event
- Previous image updates of older events are removed
- In practice, the window is segmented in pages (granularity)

The width of the sliding window increases progressively to balance smoothly between early estimation and global convergence behaviors.

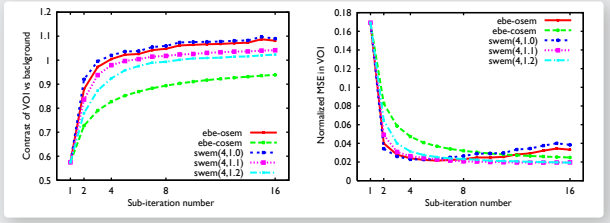


Nested Balls Phantom

The numerical phantom is defined by 4 spheres of various activity and size. A list-mode data of 8 millions events has been simulated by Monte-Carlo.

Event-by-event (EBE) variants of list-mode OSEM and COSEM are special cases of SWEM:

EBE-OSEM 1 page of 50,000 events and no window expansion (factor set to 1.0)
EBE-COSEM 16 pages of 50,000 events such that the whole 8 millions events are covered
SWEM 4 pages of 50,000 events and 10% of window expansion (factor set to 1.1)



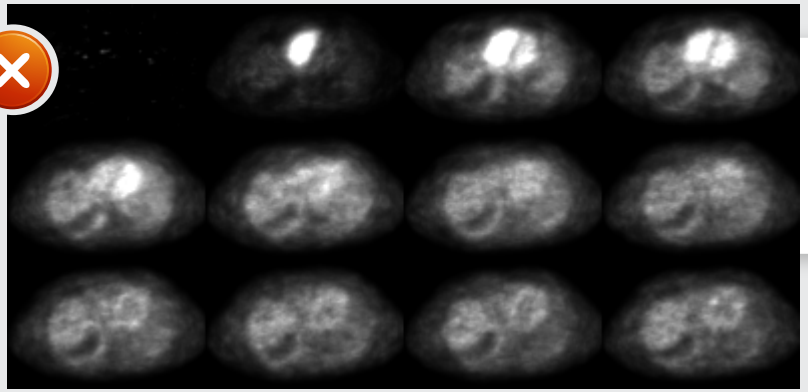
Quantitative Analyses of Static Image Reconstructions

The contrast recovery coefficient and the normalized mean squared error (MSE) from the objective image are plotted for various values of the window expansion factor between 1.0 and 1.2. The number of memory pages is fixed to only 4 for SWEM. Using more pages increases further the performances but requires more memory resources.

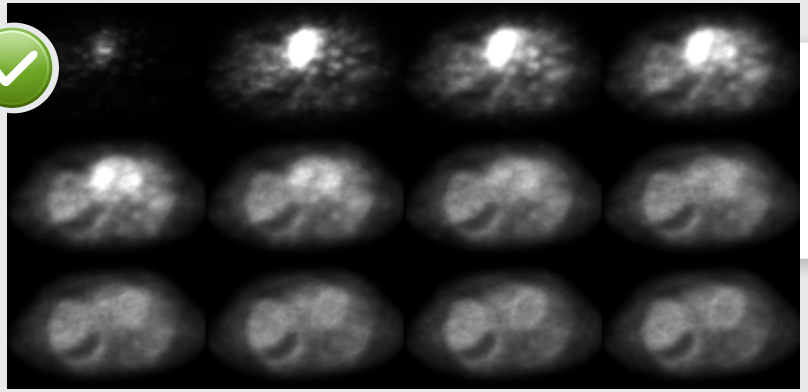
The visual contrast is defined as the ratio between the reconstructed mean activity in the small high activity ball (VOI) and the mean activity in a reference region inside the background. With an appropriate window expansion factor, SWEM prevents overfitting the data, is faster than COSEM, and yields better image quality than OSEM.

DYNAMIC CARDIAC PERFUSION STUDY

MLEM Maximum Likelihood Expectation-Maximization



SWEM Sliding Window Expectation-Maximization



Batch EM Algorithm

For each **image element**

1. *Expectation:* from **all** events compute the likelihood of **the** image element
2. *Maximization:* **multiply the** image element to improve image likelihood

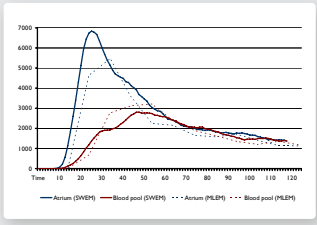
Maximum Likelihood from Incomplete Data via the EM Algorithm, 1977. A.P. Dempster, N.M. Laird, D.B. Rubin, Journal of the Royal Statistical Society. 18474 citations (Google Scholar)

Online EM Algorithm

For each **event**

1. *Expectation:* from **the** event, compute the likelihood of **all** image elements
2. *Maximization:* **increment all** image elements to improve image likelihood

A View of the EM Algorithm that Justifies Incremental, Sparse, and other Variants, 1998. R.M. Neal and G.E. Hinton, Learning in Graphical Models. 811 (+176) citations (Google Scholar)



Time Activity Curves

Comparison of dynamic image reconstructions of the cardiac ammonia perfusion study. Time activity curves (TACs) are measured at two voxels located into the right atrium and into the blood pool.

A static image is reconstructed with MLEM (32 iterations) every 10 seconds for the two first minutes of acquisition. Since SWEM (8 pages and no window expansion) reconstructs a new image for each event, all the intermediate frames are available as well.

- **Dotted** paths are linear interpolation from frames reconstructed with MLEM.
TACs are coarse and contain spurious variations (lack of temporal coherence).

- **Solid** paths are curves directly reconstructed with SWEM.
TACs are smoother and recover unambiguously the position and amplitude of peaks.

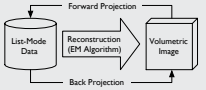
Positron Emission Tomography (PET)

The Philips Gemini PET/CT scanner acquires the attenuation image (CT) and the emission list-mode data (PET).

Detection of Coincidence Events

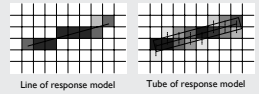
After injection, the patient is the radioactive emission source. True, Random, and Scatter coincidence events are detected.

Statistical Image Reconstruction



A volumetric image is reconstructed from acquired data. The projections operators are implemented by ray-tracing.

Tube of Response Ray-Tracer



The tube of response model is more accurate.
A fast implementation is 60% faster than incremental Siddon.

Cardiac Perfusion Protocol

A bolus of N-13 labelled ammonia is injected intravenously and a list-mode is acquired during two minutes only.

The tracer quickly enters the blood pool during the first few seconds and then passively diffuses into tissues. A dynamic image is reconstructed to capture the flow of tracer.

- MLEM performs independent static image reconstructions from batches of data acquired during 10 s (**32 iterations**).
- SWEM updates the image estimate for each event and ensures temporal coherence (**single pass** over the dataset).

Summary

This work presents a general online image reconstruction method for PET list-mode data. The online SWEM algorithm is based on event-by-event incremental image updates. SWEM improves directly the current image by exploiting the statistical information of events, as soon as they are measured.

Acknowledgments

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