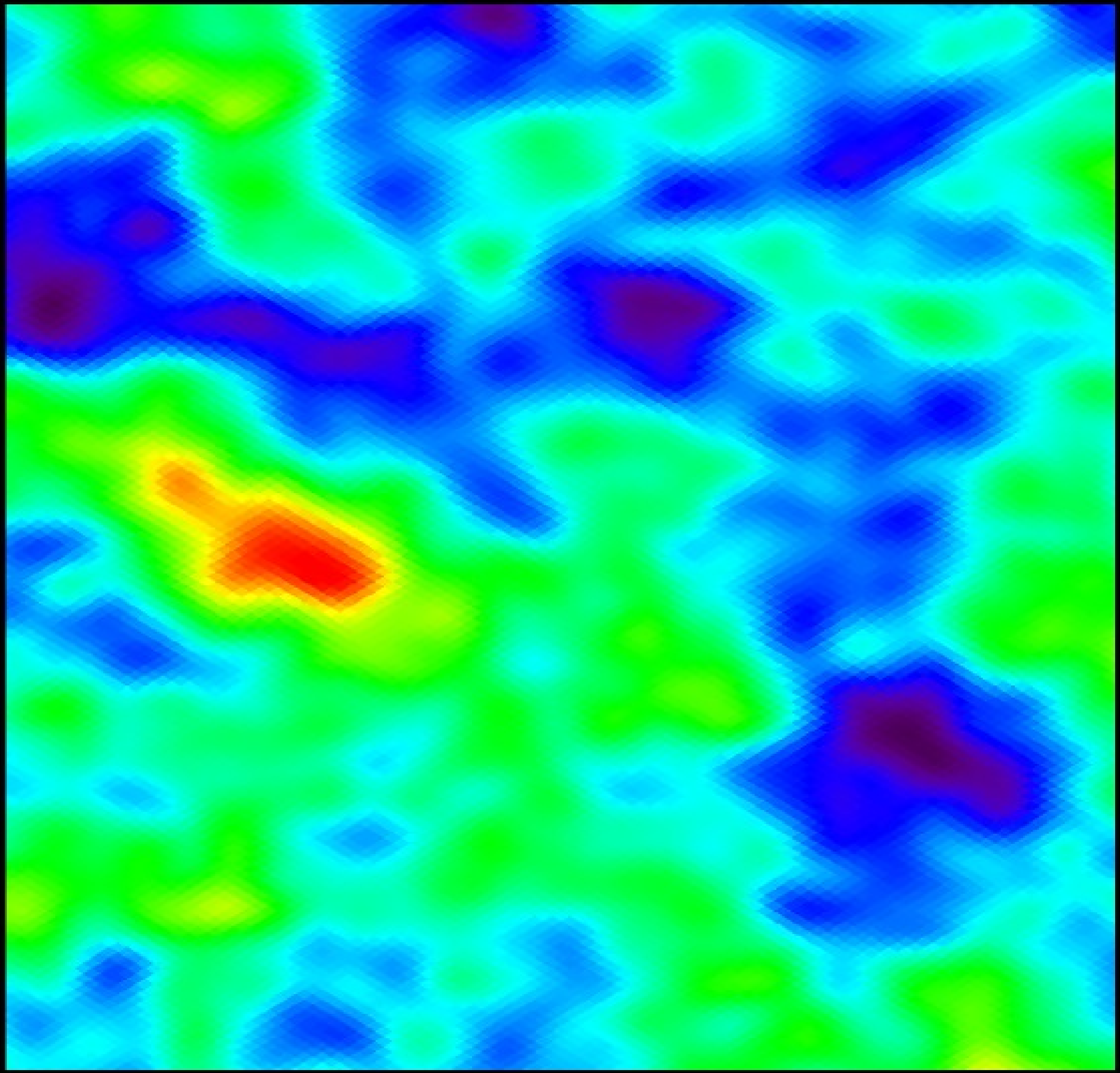
Fast Pointing Expansion for CMB Experiments



Theodore Kisner - CSE2 Interview

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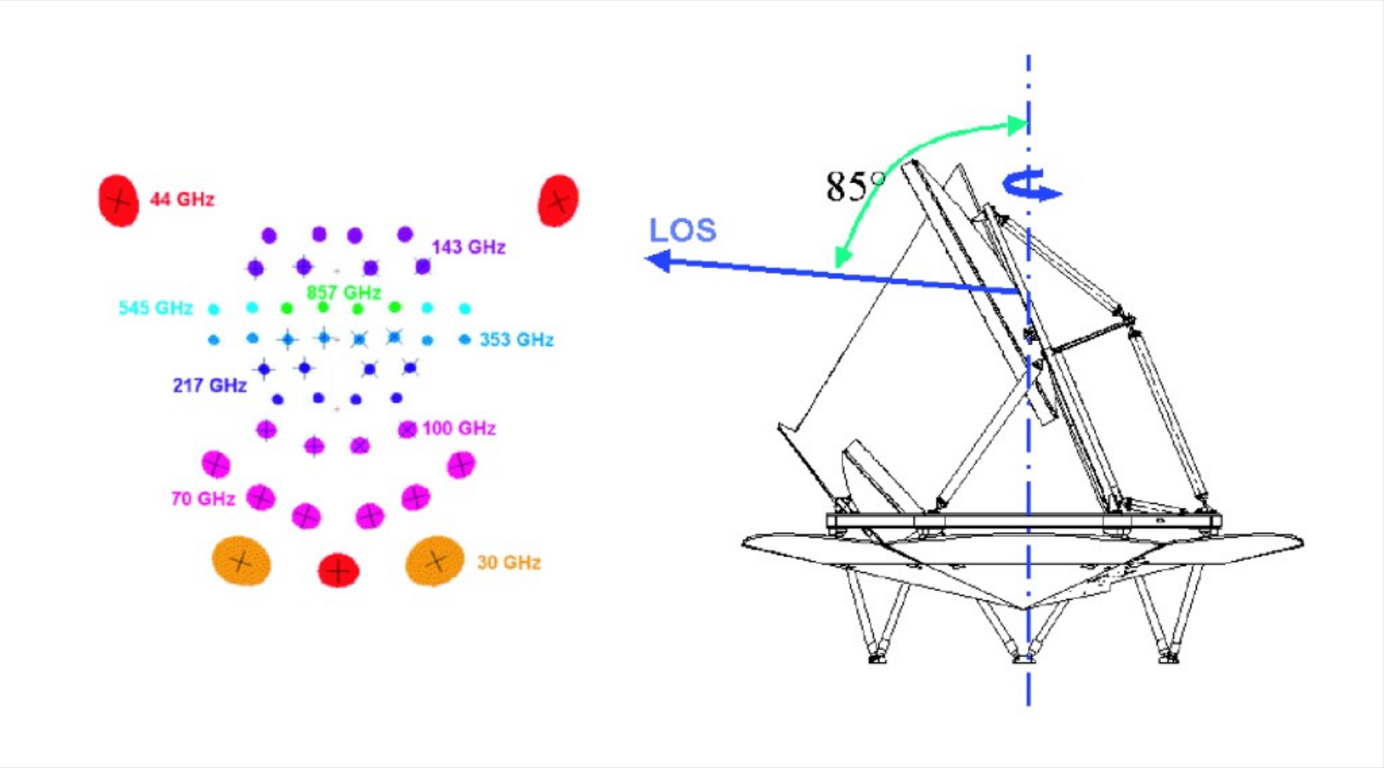
The Problem

- **Modern CMB Experiments have 100's to 1000's of detectors, sampled at hundreds of Hertz**
- **Analyzing the resulting data requires the direction and orientation of each detector on the sky, for each sample**
- **Storing all this pointing information on disk is impractical**
- **Computing this information on-the-fly can potentially dominate the computational cost of the analysis**
- **Can we find a technique and optimizations to make this a sub-dominant computation?**

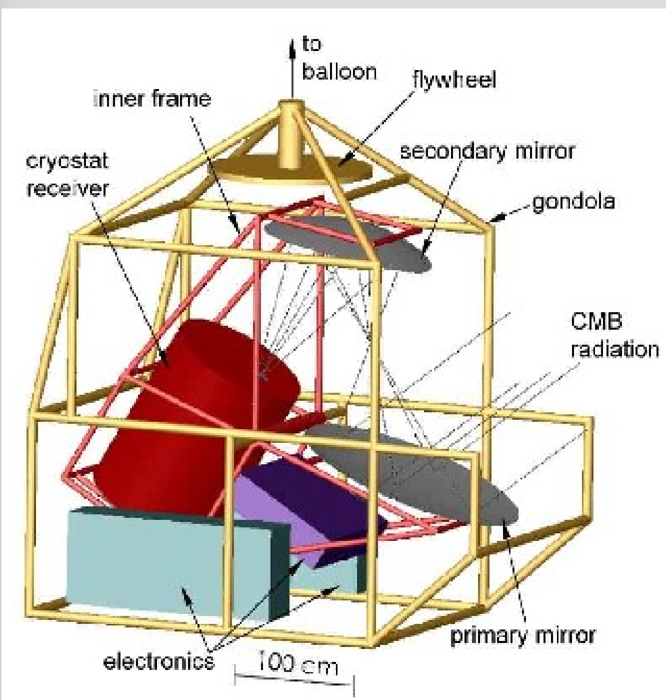
Example #1 - The Planck Satellite

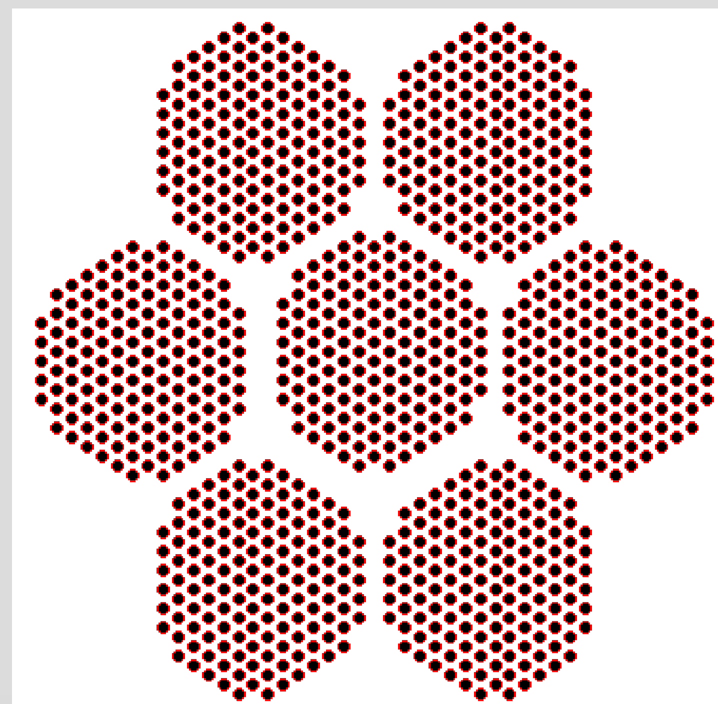
- **74 detectors sampled at 32Hz-200Hz**
- **Telescope pointing (sampled at 1Hz) is given as satellite spin axis direction and orientation around this axis**



Example #2 - The EBEX Balloon Experiment

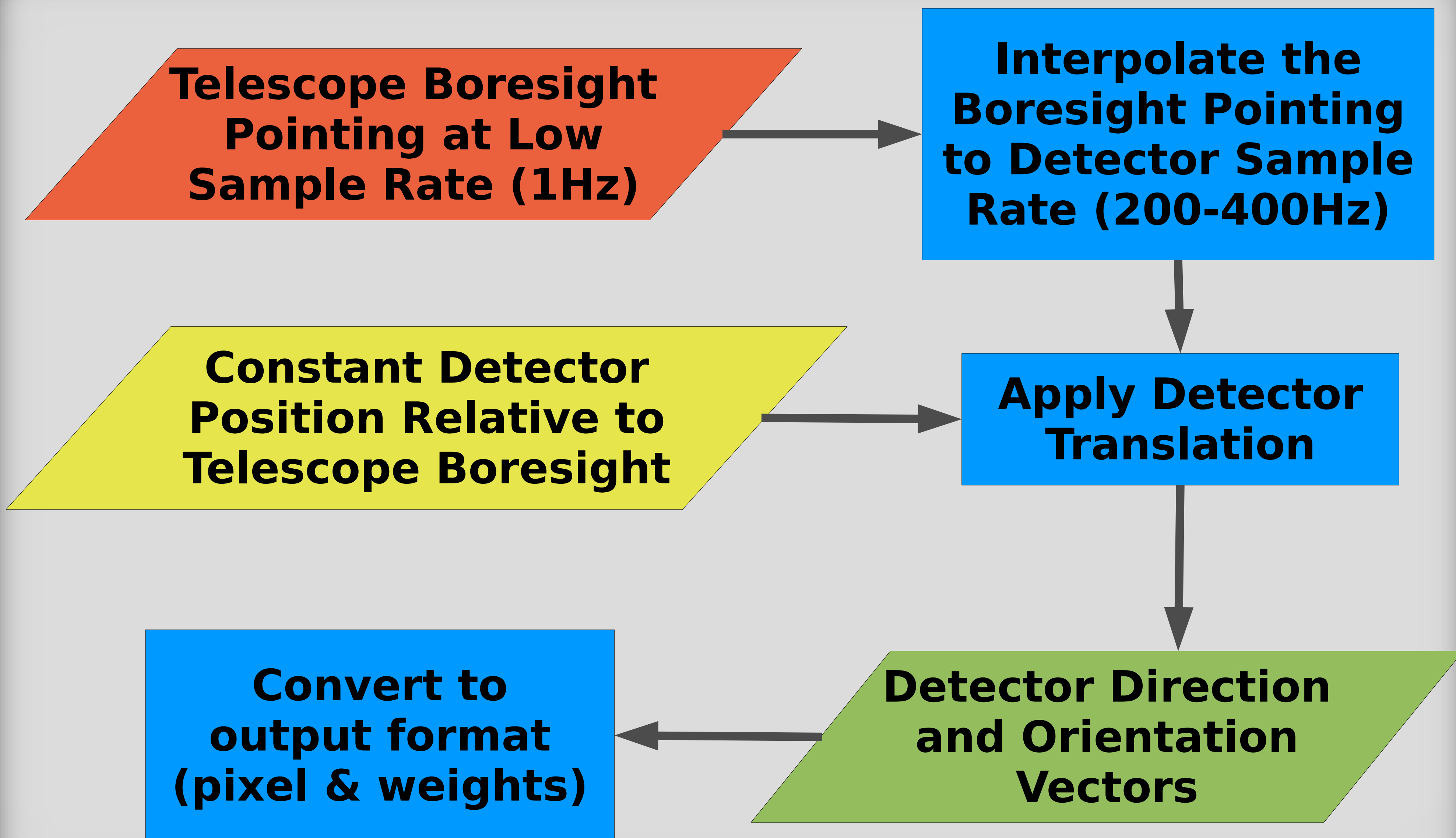
- **Approximately 1400 Detectors Sampled at 400Hz**
- **Telescope boresight pointing sampled at a variable rate to account for the scanning motion (more samples at the turnarounds)**





X 2

Inputs and Outputs



Overview of Method

At First Glance, apply 3x3 rotation matrices:

$$\begin{pmatrix} \text{Direction} & \vdots & \text{Orientation} \end{pmatrix} = \begin{pmatrix} \textit{Absolute}\text{ Rotation from} \\ \text{Boresight to Detector} \end{pmatrix} \begin{pmatrix} \text{Interpolated }\textit{Absolute} \\ \text{Rotation from} \\ \text{Axes to Boresight} \end{pmatrix} \begin{pmatrix} 0 & \vdots & 1 \\ 0 & \vdots & 0 \\ 1 & \vdots & 0 \end{pmatrix}$$

But Much Better is:

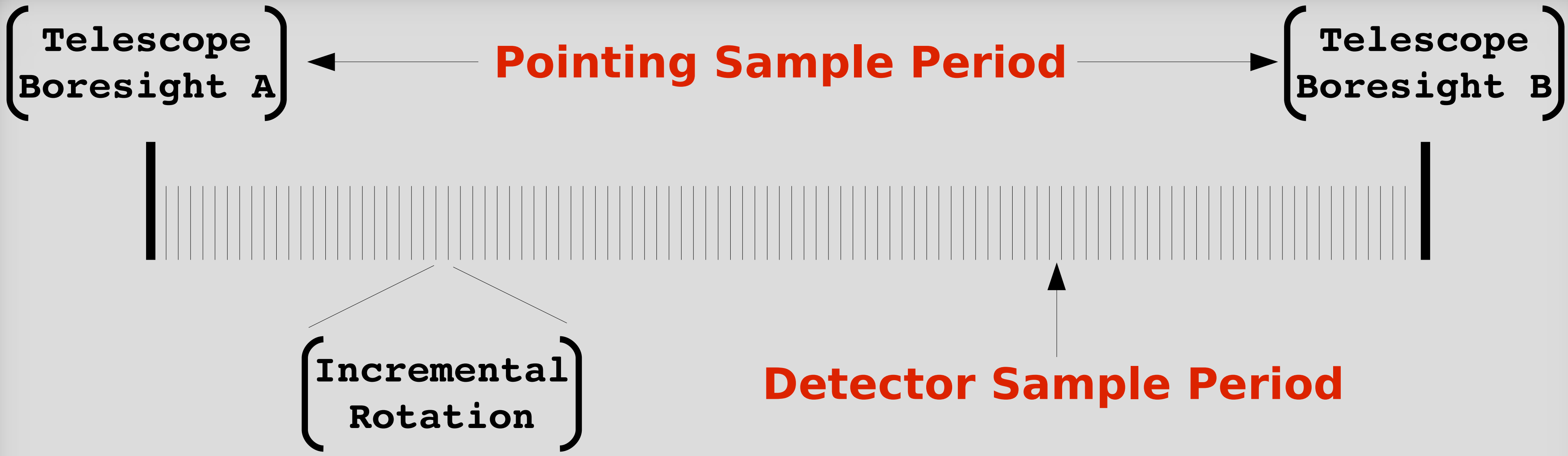
$$\begin{pmatrix} \text{Direction} & \vdots & \text{Orientation} \end{pmatrix} = \begin{pmatrix} \text{Interpolated }\textit{Relative} \\ \text{Rotation from} \\ \text{Axes to Boresight} \end{pmatrix} \begin{pmatrix} \textit{Relative}\text{ Rotation from} \\ \text{Boresight to Detector} \\ \text{(Constant)} \end{pmatrix} \begin{pmatrix} 0 & \vdots & 1 \\ 0 & \vdots & 0 \\ 1 & \vdots & 0 \end{pmatrix}$$

Do These in a Buffered Way

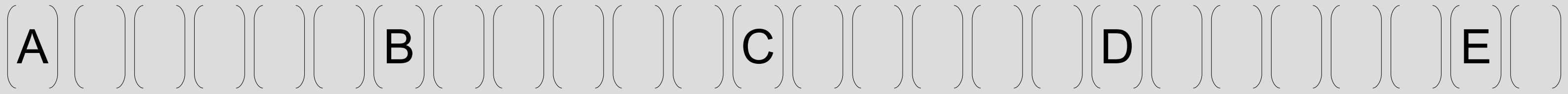
Precompute Once

Pixel Index and Orientation Quantities

Step #1 - Interpolation

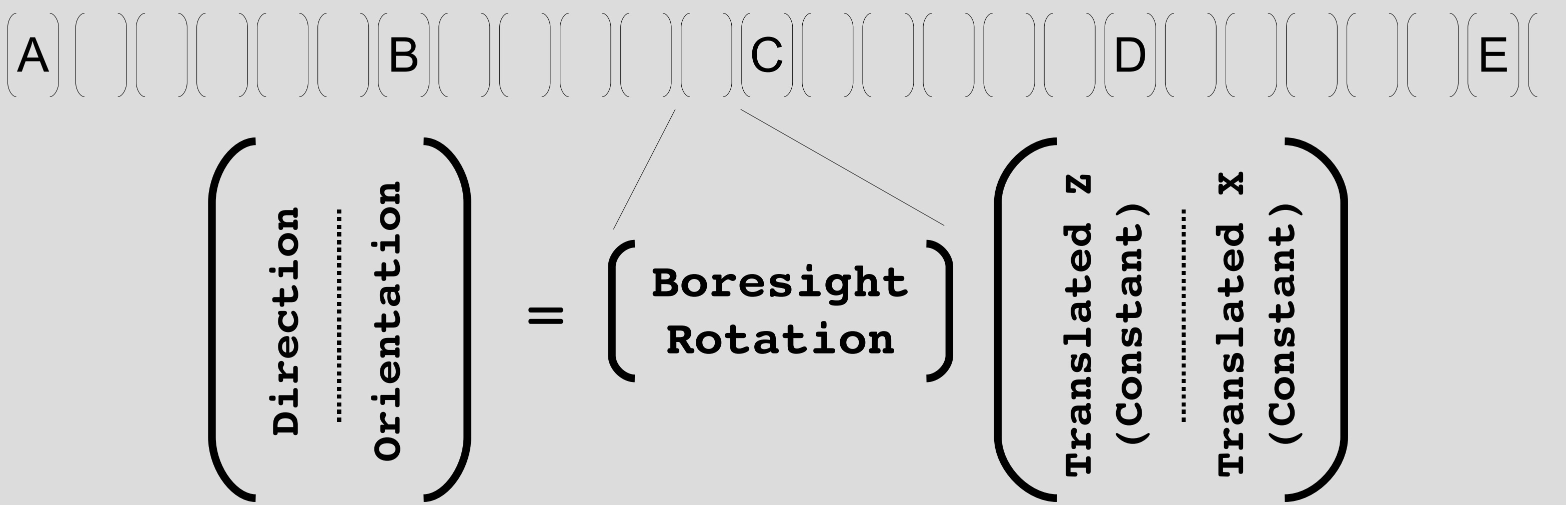


Repeatedly apply incremental rotation to obtain boresight rotation matrix for each detector sample (27 FP multiplies per detector sample). Build up a buffer of these matrices.

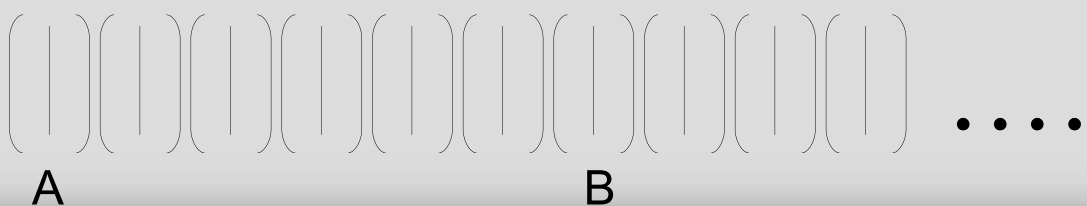


Step #2 - Detector Pointing

For each sample in the buffer, apply matrix to 2 precomputed detector translation vectors (18 FP multiplies).



Resulting pairs of vectors are stored in a separate buffer:



Step #3 - Conversions

- Use minimal number of transcendental functions needed to convert to desired output format.
- Construct buffers of quantities from the detector direction and orientation vectors.
- Apply system-specific vector math routines (MASS, ACML, MKL).
- If no library available, use Taylor expansion.

EXAMPLE:

<u>HEALPix Pixel # and Polarization Weights</u>

2 • sqrt

atan

Relative Wall-Clock Comparison

7.02e10 samples (Interp / Conv / Total Sec.)	Bassi	Franklin	Davinci
libm	17.5/104.0/121.5	9.1/34.0/43.1	‡18.2/33.3/51.5
Taylor (atan)	17.5/38.9/56.4	9.1/26.7/35.8	‡18.4/45.8/64.2
MASS (atan/sqrt)	17.4/19.1/36.5	----	----
ACML (NA)	----	‡9.2/26.6/35.8	----
MKL (atan/sqrt)	----	----	‡18.4/28.7/47.1

‡Davinci is a shared resource machine
‡ACML is not actually used for vector math here

Conclusions

- **Performance is more than twice as fast as existing code, and is usually 10% - 20% of the computational cost of a CMB map-making analysis.**
- **Future Work**

1) Support arbitrary detector beams - do a fast lookup of values from a beam profile and return quantities for a set of neighboring pixels.

3) Add new functions for experiment-specific quantities.

4) Improve the API to make extensions easier.