Issues Regarding fMRI Imaging Workflow and DICOM

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What is fMRI

- fMRI is used to localize functions to different parts of the neuroanatomy

- It consists of:
  - A higher resolution anatomical scan (e.g. T1)
  - Followed by a time series of lower resolution scans (e.g T2*) done
    - Every 2-5 seconds
    - While the subject is performing various tasks
    - For tens of minutes

fMRI basic principles

- Function → energy consumption → rCBF

    - A functional map is set upon an anatomical image
    - Anatomical image formed based on magnetic properties of tissue
    - Functional image formed based on magnetic properties of blood flow

Salient Features of the Acquired Data

- These datasets are HUGE!

- Knowledge of the experimental protocol is crucial for the analysis of the data

- Substantial post processing is needed to extract the information of interest

- The extracted information can be visualized in a variety of ways

Simplified fMRI Workflow
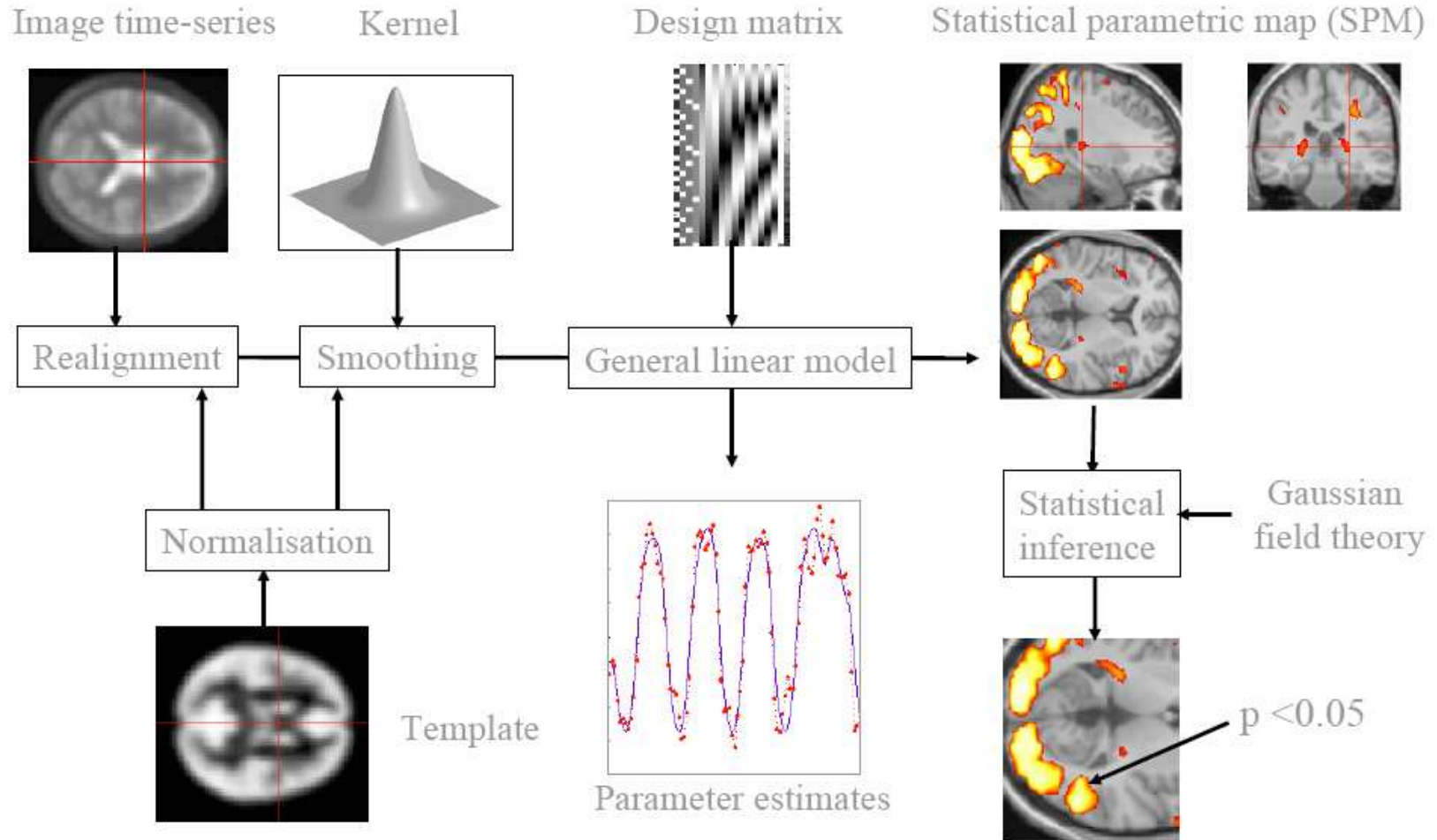
Acquire → Process → Visualize

Images in DICOM Format
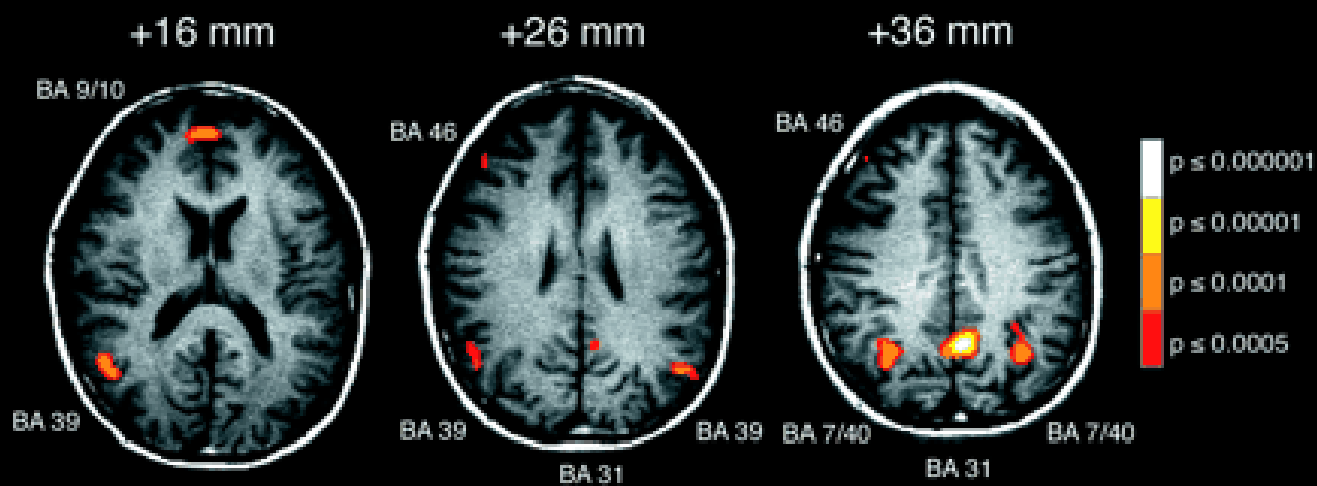
Images in Processing Format (not DICOM)

Images in Visualization Format (not DICOM)
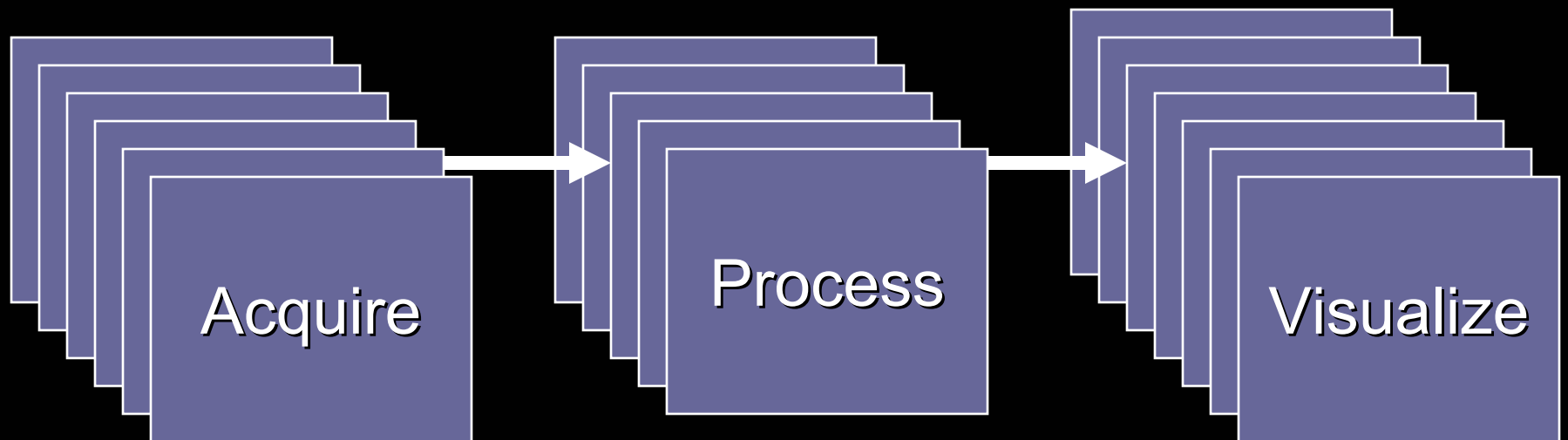
Generally the same format,
Often proprietary

Data analysis

From Karl J. Friston,"Introduction – Experimental Design and Statistical Parameter Mapping"
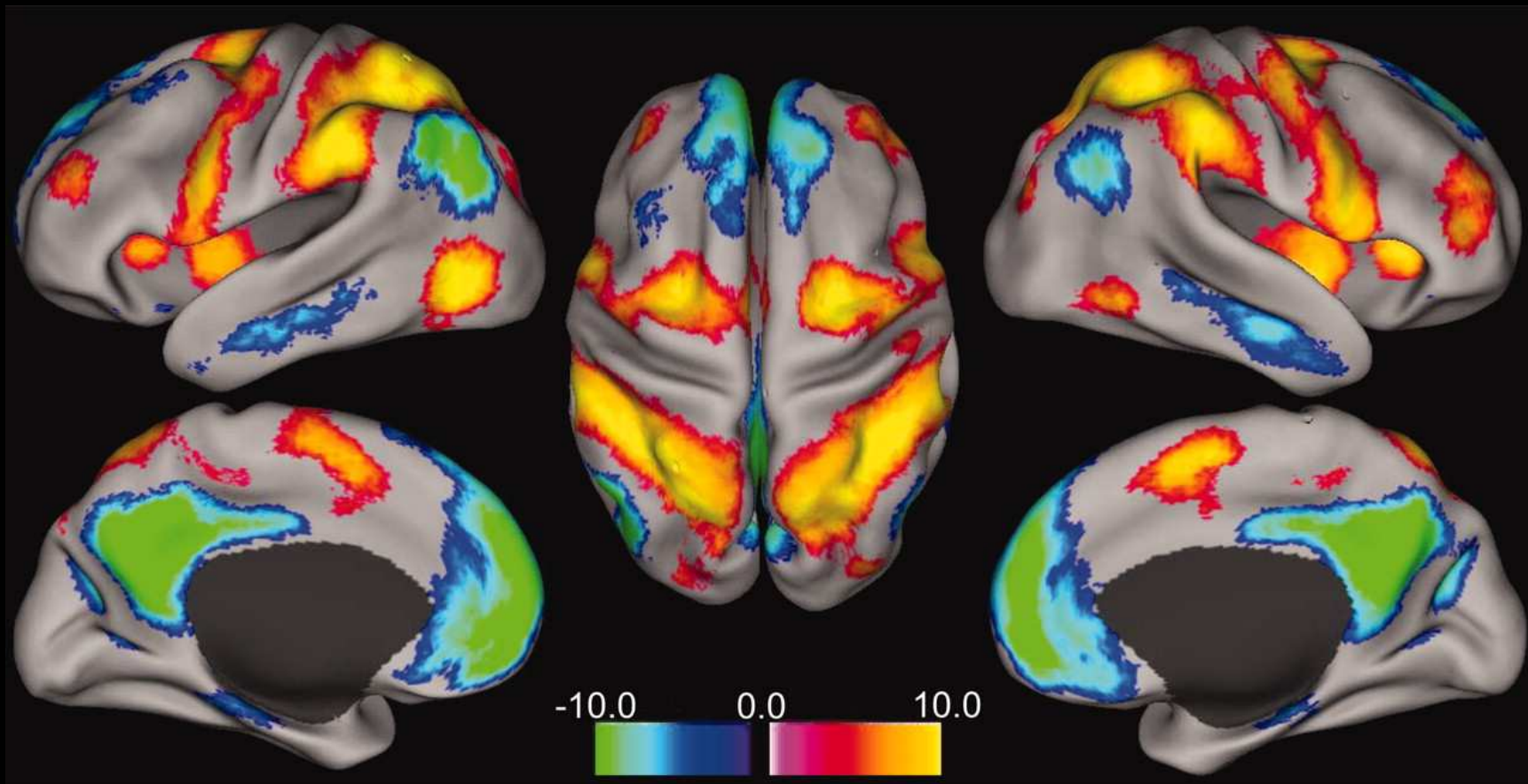http://www.fil.ion.ucl.ac.uk/spm/doc/intro/intro.pdf

Likely fMRI Workflow

Acquire → Process → Visualize

Images from
Multiple Patients

Transformed to
Standardized Atlas
Coordiates,
Processed in
Multiple Ways

Visualized in
a Variety
of Forms

Basic Interoperability Problem

- Researchers often exchange intermediate post-processing targets
  - Alternate Analysis
  - Population Studies (warped to standard atlas (e.g. MNI or Talairach) and combined)
- Data in the visualization format also often exchanged
- The processing and visualization formats at different sites are not always compatible, nor is there a standard means for communicating the experimental protocol

Quote from the NIfTI Web Site

"… many existing tools have been developed piecemeal, by scientists who are interested in answering particular neuroscience questions rather than in producing software products that are optimized for meeting the many and varied needs of the broader research community.

"… This Tower of Babel problem raises important concerns about compatibility between different tools; it also limits the ability of scientists to rigorously compare their findings, which is the foundation upon which progress in science is built."

Competing fMRI formats

- **Analyze/SPM**
  - http://www.mayo.edu/bir/PDF/ANALYZE75.pdf
- **MINC**
  - http://www.bic.mni.mcgill.ca/software/minc/minc.html
- **AFNI**
  - http://afni.nimh.nih.gov/
- **Various lab-specific formats**
- **NIfTI** (pushed by NIH)
  - http://nifti.nimh.nih.gov/

NIfTI
Neuroimaging Informatics Technology Iniative

- The primary goal of NIfTI is to speed the development and enhance the utility of informatics tools related to neuroimaging.
- First developed a data format – NIfTI-1
  - Based on the Analyze 7.5 file format
  - Developed to "foster interoperability at the file-exchange level between FMRI data analysis software packages" (http://nifti.nimh.nih.gov/nifti-1/)
  - Data Format Working Group (DFWG) has the task to evolve the format in an attempt to solve the problem posed by the multitude of data formats used in fMRI research
- The National Institute of Mental Health and the National Institute of Neurological Disorders and Stroke are joint sponsors of this initiative.

NIfTI-1 File Format – Key features

- Two affine coordinate definitions relating voxel index to spatial location
- Codes to indicate spatial normalization type: MNI, Talairach
- Codes to indicate units of spatio-temporal dimensions
- Codes to indicate spatio-temporal slice ordering
- Pixel definition up to 128 bits per pixel
  - Signed or unsigned integer
  - Floating point and complex
- Standardized method for storing vector-valued datasets
- Codes and parameters to indicate data "meaning", e.g.
  - Values are t-statistics or Z- scores
  - 21 coded values for different parametric distributions
  - Ability to represent multiple values at each voxel (e.g. matrix or vector per voxel)
- Ability to separate the header and voxels into separate linked files
- Potential future extensions:
  - Experimental Designs Matrices
  - Geometry and Surfaces
  - Non-linear warps
  - Diffusion Data

From: Cox et. al., 2004 - http://nifti.nimh.nih.gov/nifti-1/documentation/hbm_nifti_2004.pdf

Why didn't NIfTI just use DICOM?

- "The committee felt that DICOM did not satisfy the general requirements of a simple format for the fMRI community with DICOM's large, clinically focused storage overhead and the relatively complex specifications for multiframe MRI and spatial registration. In addition, the DICOM specification is also heavily concerned with data communication, something the committee felt was well beyond the scope of NIfTI-1."

NIfTI-1 FAQ:http://nifti.nimh.nih.gov/nifti1/documentation/faq#Q2

New DICOM Multiframe MRI object

- Addressed some concerns, e.g.
  - Easier management of large multi-dimensional volume sets
  - Easier access to volume pixel data
  - Special LUTS
- Missed other concerns, e.g.
  - Certain parameters that fMRI scientists need
  - Floating point pixel types
  - Display of floating point pixels (e.g. FP LUTS)
  - Volume sets of varying dimensions

Recommendations

- Engage the fMRI community as partners wishing to help them solve the interoperability problem
  - Incorporate NIfTI's semantics into DICOM
  - Incorporate methods for exchanging protocol descriptions (design matrices)
- Training, demos, or examples of how fMRI data is encoded in DICOM
- Encourage tools that directly utilize a DICOM fMRI format

Questions?