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virtual laboratory for e·science

Large Scale functional MRI Parameter Study on a Production Grid

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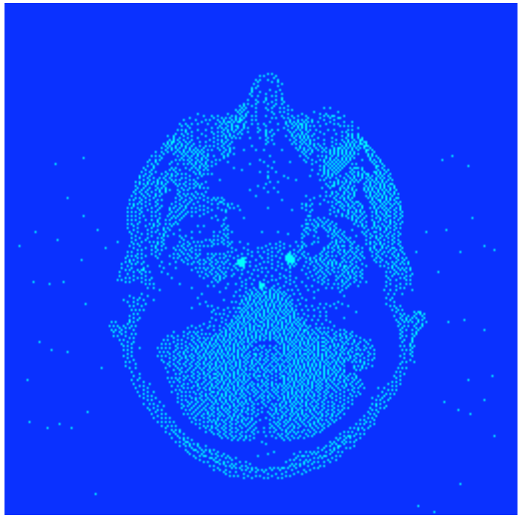
Overview

- Intro functional MRI
- Parameter study
  - Data, methods
  - Grid implementation
- Results
- Current status and prospects

Functional MRI (fMRI)
Blood-Oxygen-Level Dependent (BOLD)

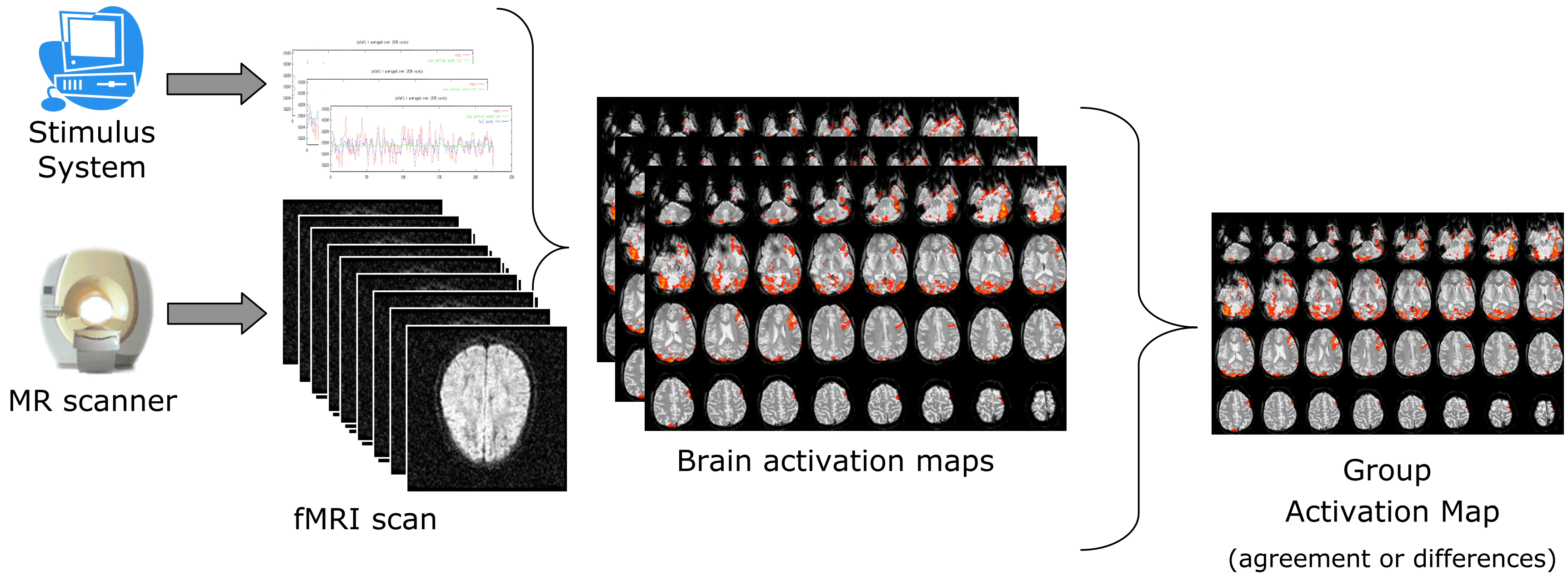
- fMRI measures brain activity indirectly through changes in the oxyhaemoglobin/deoxyhaemoglobin ratio
  - Increased local perfusion due to neuronal activity
- Statistical analysis used to calculate

activation maps



In color:
standardised activation probabilities (Z-score)

fMRI: Dataflow



fMRI: Difficulties

- Complex acquisition
  - Stimulus (task)
  - Imaging protocol
- Complex image analysis pipeline
  - Data normalization (temporal, intensity, spatial corrections)
  - Statistical analysis
  - Registration (alignment to anatomical and reference scans)
- Various software packages:
  - fMRIB Software Library
  - Statistical Parametric Mapping
- Many parameters, how do they influence results?

This study

- Neuroscience questions:
  - How are results (brain activation) influenced by the choice of selected parameters values?
  - Will an MRI-sequence with a smaller echo time (TE) change the measured activation within the brain?
- Approach:
  - FSL fMRI Expert Analysis Tool (feat)
  - Compare mean and difference of activation in the amygdalae in activation maps calculated with various parameters
  - Adopt grid to enable data analysis

    (1 CPU-year and 1.4 Terabytes of data)

Subjects and scans

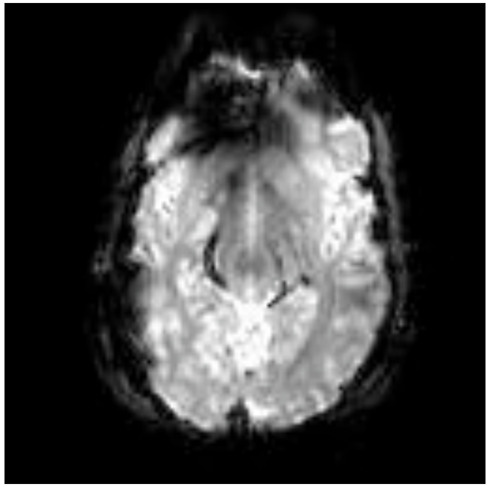
- 11 healthy volunteers
- Emotional task:
  - International affective picture system (IAPS)
    - mutilations, snakes, insects, attack scenes, accidents, contamination, illness, loss, pollution, puppies, babies, and landscape scenes
  - Robust activation of amygdalae
- Two MRI sequences
  - Philips 3.0 Tesla Intera scanner
    - Echo time (TE) =28 ms, repetition time (TR)=2.7 s
    - TE=35 ms, TR=3.1 s

Parameter:
Echo time (TE) for image acquisition

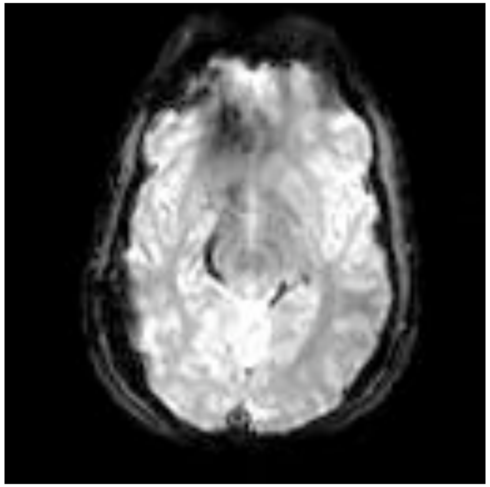
- *time window between the transmission of a radiofrequency pulse and the signal acquisition in fMRI*
- shorter echo time tends to generate
  - higher signal, smaller susceptibility artifact
  - lower contrast between high and low brain activity states

- Different activation?
  - 35, 28s?

TE= 40ms



TE= 25ms



Parameter:
Width of spatial smoothing kernel

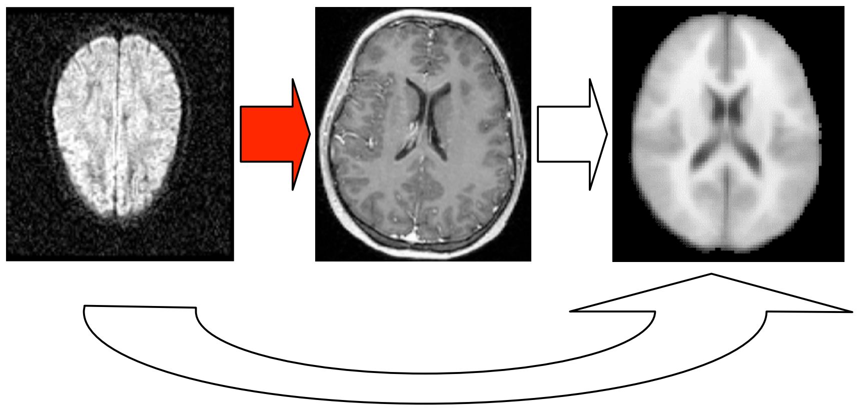
- Data is smoothed in the preprocessing phase
  - Gaussian kernel
- This increases signal to noise ratio (SNR), improving sensitivity.

- Optimal size (σ) of smoothing kernel?
  - 2,3,4,5,6,7,8,9,10,11,12 mm

Parameter:
Degrees of freedom for affine registration

- Registration from fMRI data to MNI standard brain
- Control search space for registration algorithm (FSL FLIRT)
  - Translation, rotation, scaling and shear
  - Larger freedom sometimes produces wrong results (flip)

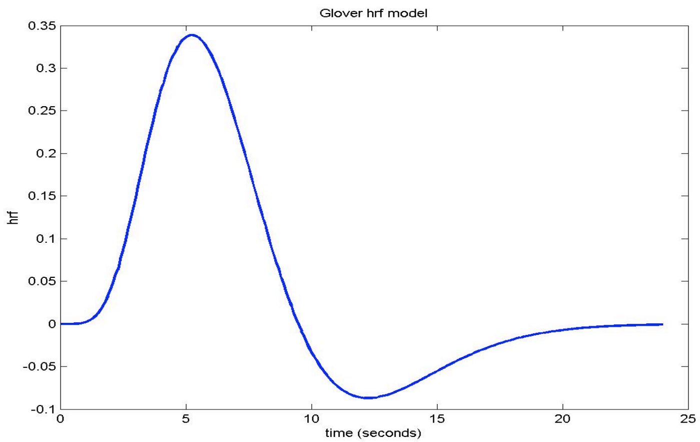
- Number of degrees of freedom for fMRI to anatomical?
  - 3,6,7,9,12



Parameter:
Delay in hemodynamic response function (HRF)

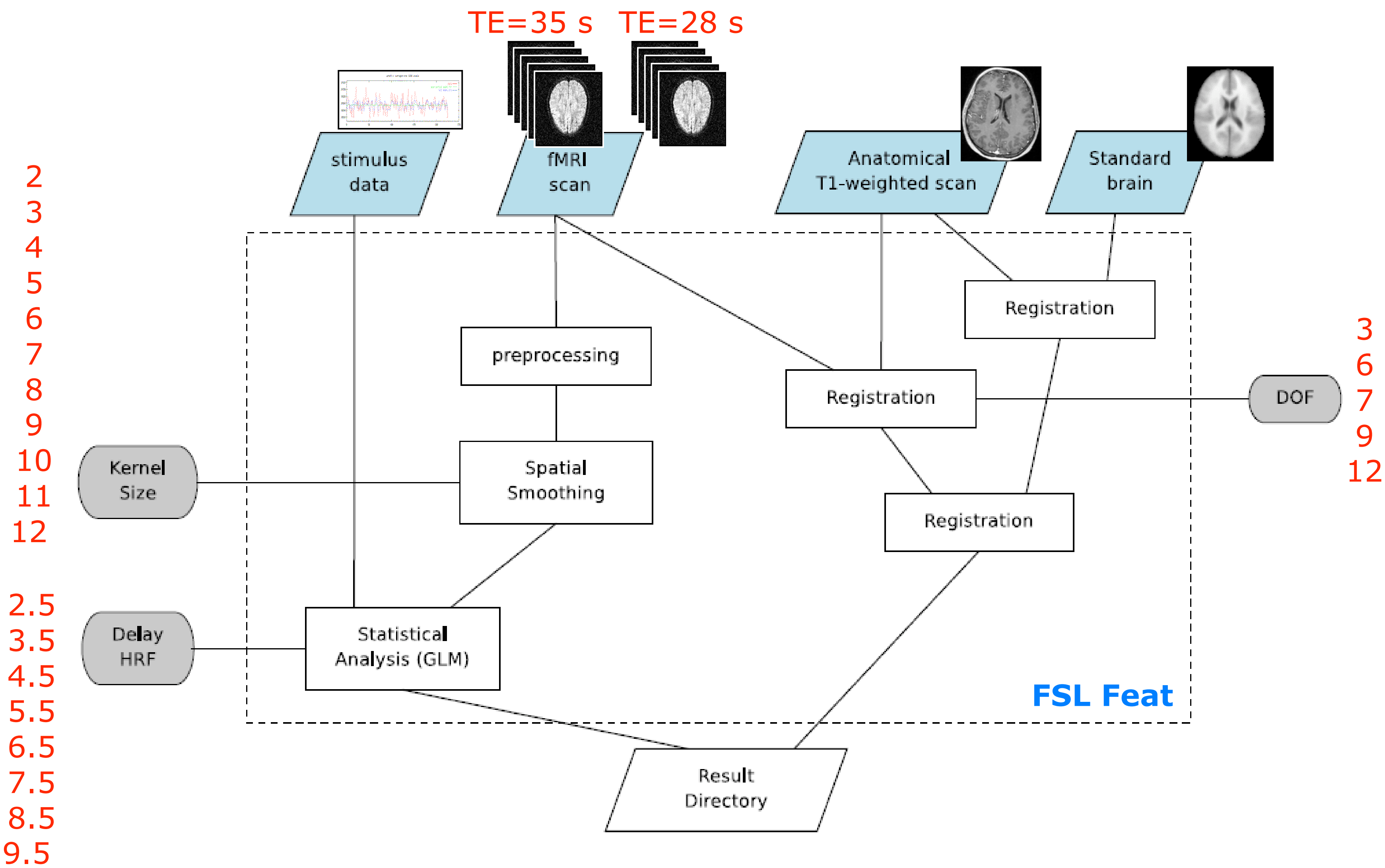
- Statistical Analysis based on

  General Linear Model (GLM) analysis
- Fit data to model



- Best "delay"?
  - 2.5,3.5,4.5,5.5,6.5,7.5,8.5

Parameter Sweep: Overview

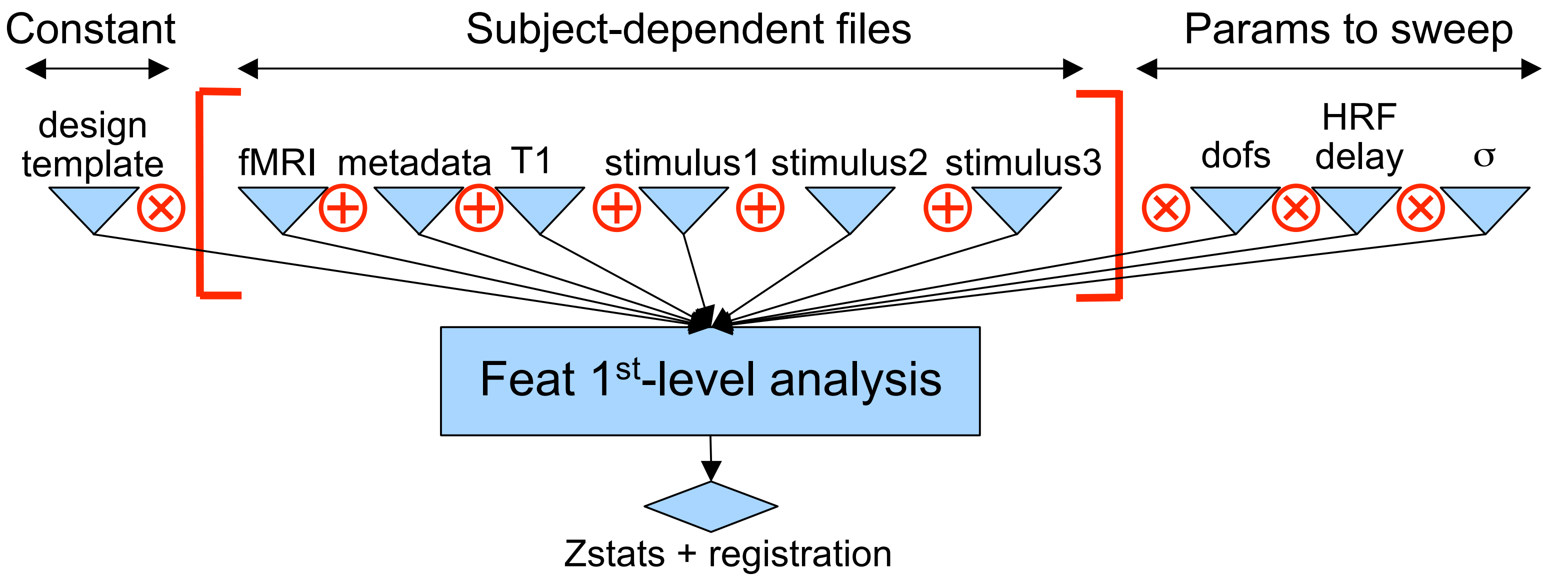


Parameter sweep: Application deployment

- Legacy software (e.g., FSL feat) wrapped as workflow components
- Workflows
  - described in Scufl (Tarverna workbench)
  - executed with MOTEUR on gLite infrastructure
  - Two workflows: Individual and group analysis
- All data stored on grid resources
- Front-end: VBrowser

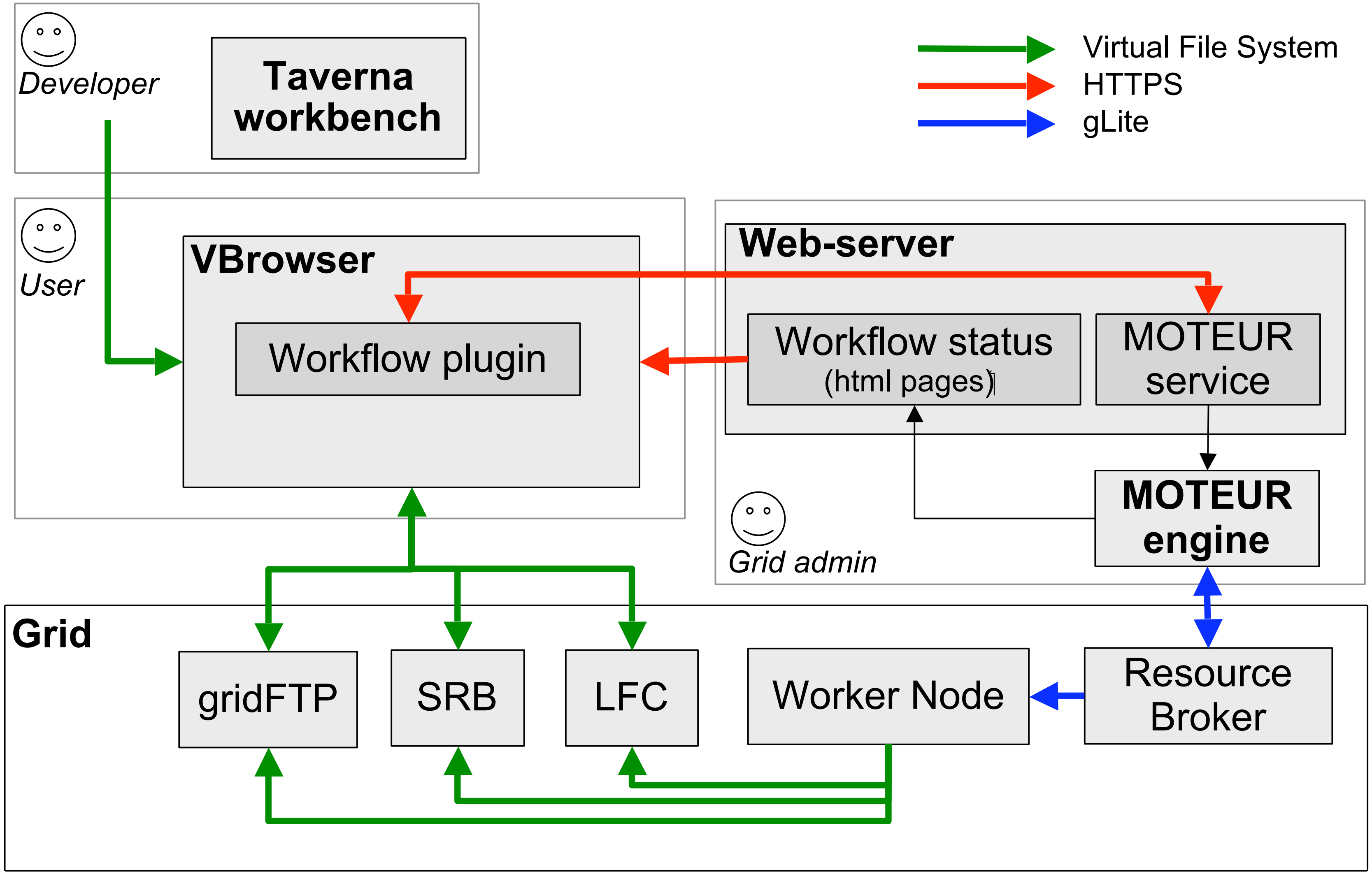
Workflow as parameter sweep engine

- Individual analysis



- Similar set-up for group analyses

Workflow Execution



Connectivity from Hospital to Grid

Infrastructure

- Virtual Laboratory for e-Sciences Project (VL-e)
  www.vl-e.nl
- VL-e PoC / BIGgrid
  - gLite
  - EGEE
  - LifeSciences Grid
- Capacity
  - 8 sites (SE,CE)
  - 2150 nodes
  - >20? TBytes
  - Updated continuously

The experiment

- 9600 individual analyses
  - 45 min, 160 MB per analyse
  - 11 patients ; 2 echo times
  - 5 dof values (3, 6, 7, 9, 12)
  - 11 smoothing values (2 to 12mm step 1mm)
  - 17 phase values (2.5s to 9.5s step 0.5s)
- 880 group analyses => 13 CPU days / 0.05 TB
  - 10 min, 27 MB per analyse
- 440 group differences analyses

- Computed in 7.4 days

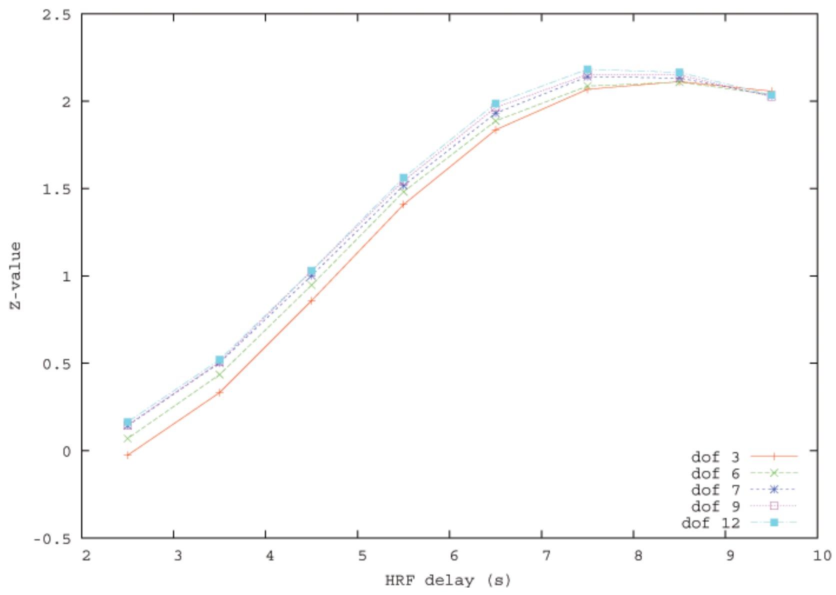
Results: execution on the grid

	$\#P_i$	#T	#S	#D	#H	# Analyses	CPU (days)	Data (TB)	Elapsed (hours)	Speed -up	# Submit Jobs	Failure (%)
Individual Analyses												
batch 1	11	1	5	5	8	2200	74.9	0.31	14.9	120.5	2200	0.00
batch 2	11	1	6	5	8	2640	89.8	0.38	11.6	186.6	2642	0.08
batch 3	11	1	6	5	8	2640	89.8	0.38	32	67.38	2687	1.75
batch 4	11	1	5	5	8	2200	74.9	0.31	10.2	176.8	2203	0.14
total	11	2	11	5	8	9680	329.4	1.38	68.7	115	9732	0.53
Group Analyses								(MB)				
batch 1		1	6	5	8	240	1.4	7.1	8.0	4.3	401	40.15
batch 2		1	6	5	8	240	1.4	7.1	9.5	3.6	240	0.00
batch 3		1	5	5	8	200	1.2	6	14.9	1.9	200	0.00
batch 4		1	5	5	8	200	1.2	6	11.3	2.5	600	66.67
total		2	11	5	8	880	5.2	26.2	43.7	2.9	1441	38.93
Group Difference Analyses								(MB)				
batch 1			11	5	8	440	7	23.8	44.3	3.8	2650	83.40

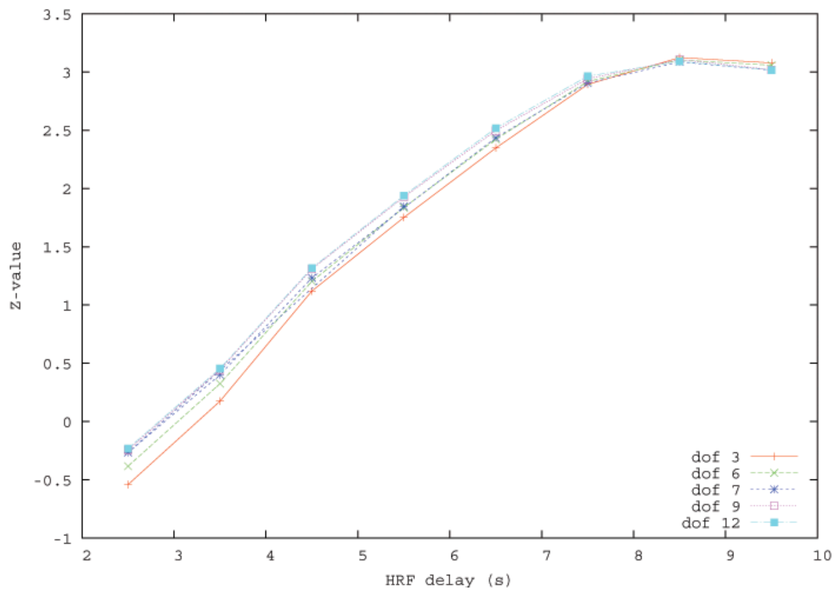
Results:
Degree of freedom (fMRI to anatomical registration)

- No significant difference

σ=5 mm

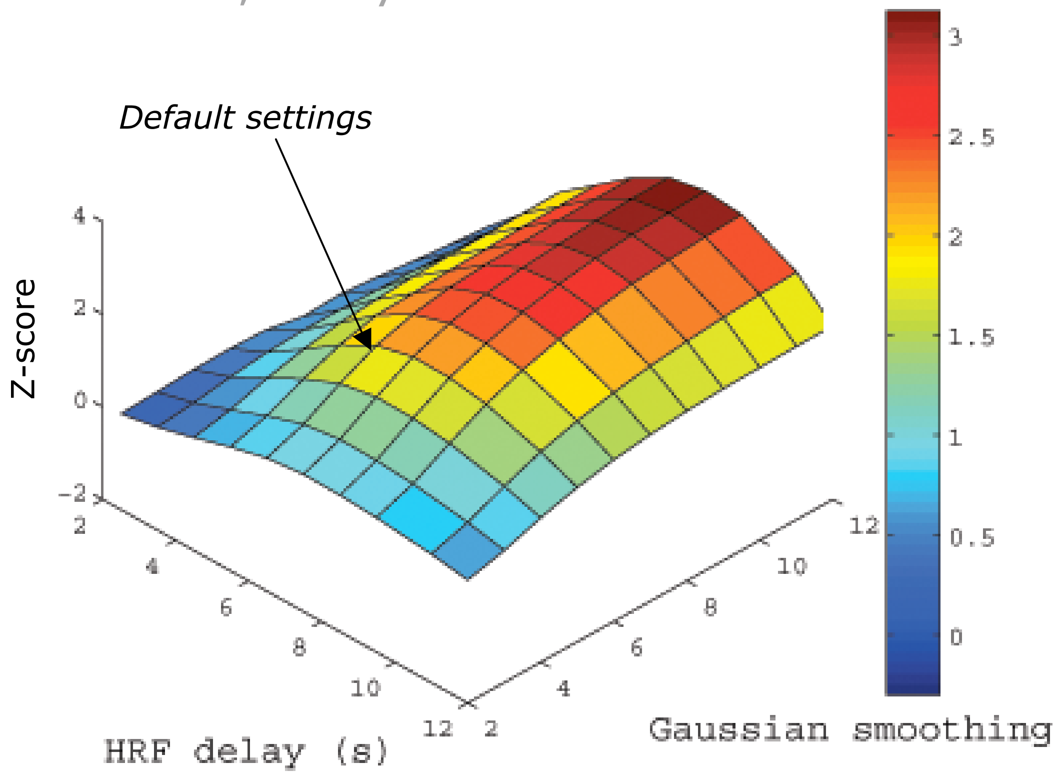


σ=11 mm



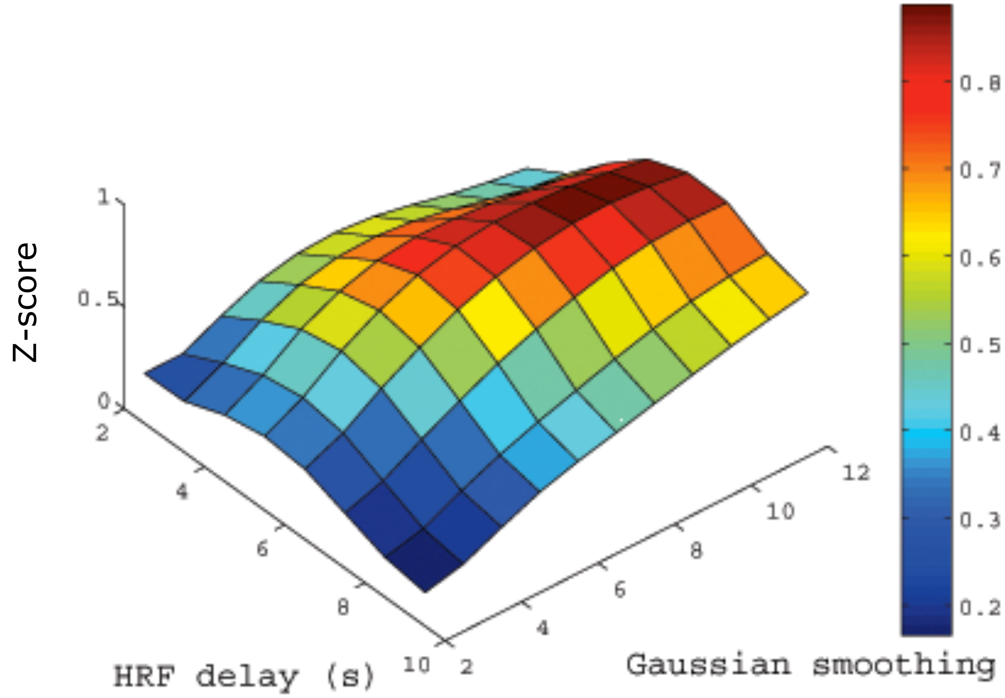
Results:
HRF delay vs. smoothing kernel size

- Optimal for amigdalae different from standard values
  - smooth=5 mm, delay HRF=6 s



Results:
Echo time (TE)

- No significant difference for any parameter combination
  - *Significance: Z-score > 2.3 (p=0.01)*



Conclusions: Neuroscience

- Optimal HRF delay to detect amygdalae differs from default parameter settings
  - What about other regions?
- Differences not significant for
  - Degrees of freedom in registration fMRI to anatomical
    - What about anatomical to standard brain?
  - Echo time
    - Robust conclusion based on a large analysis effort
- Impact of smoothing to be further investigated

Conclusions: Grid

- Feasible to use grid implementation in a real scenario
  - proof-of-concept of large experiment
  - Proof-of-concept to non high-energy Physics application
- Grid implementation as enabling factor
  - Potential illustrated to end users
  - New studies being autonomously designed and executed on the grid by the user
- Still needs much expert intervention to
  - Adapt workflows
  - Keep services alive (MOTEUR, VBrowser-related)
  - Troubleshooting

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Discussion: Ready for users?