Brain Perfusion Imaging
- Performance and Noise Reduction

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Outline

- Perfusion Imaging Introduction
- Performance in Perfusion Imaging Process
- Noise Reduction in Perfusion Imaging

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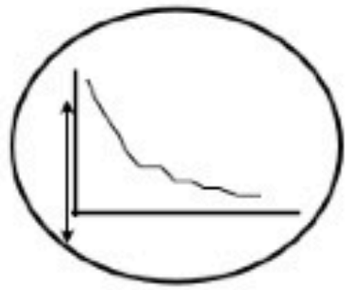
What is Perfusion Imaging

$$CBF = Max(h)$$

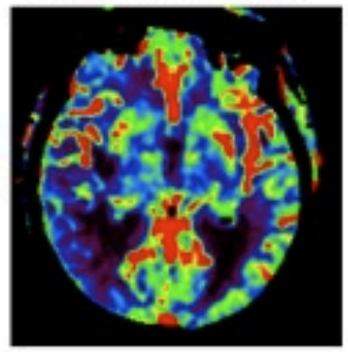
$$CBV = \int_0^\infty h(t)\,dt$$

$$MTT = CBF/CBV$$

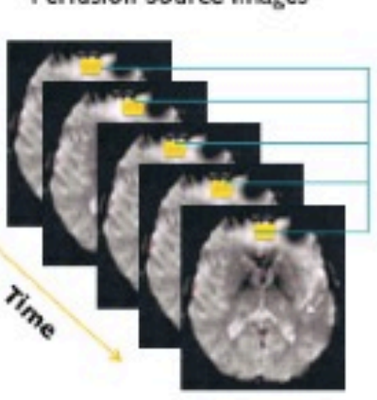
Maximal Value



Cerebral Blood Flow

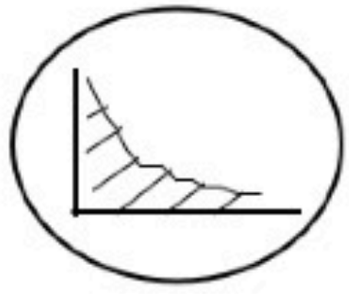


Perfusion Source Images

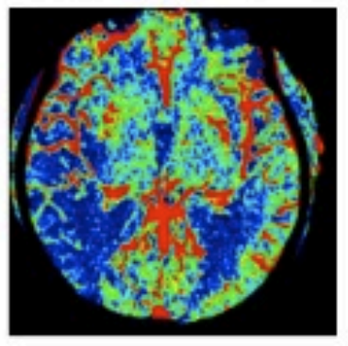


Tissue Time-Concentration Curve

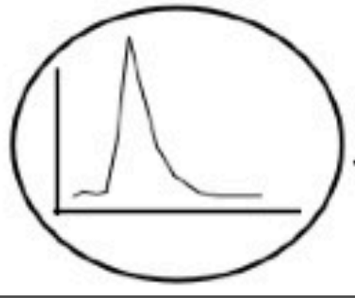
Area



Cerebral Blood Volume

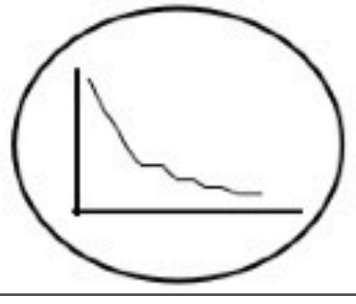


Arterial Input Function (AIF)

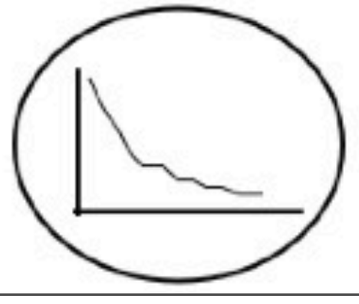


Deconvolution

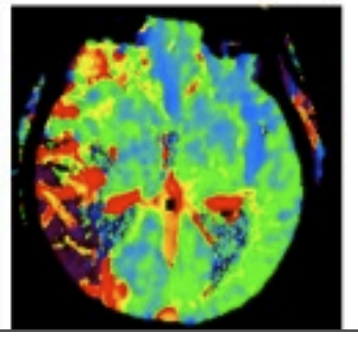
Tissue Response Function



Area / Maximal Value

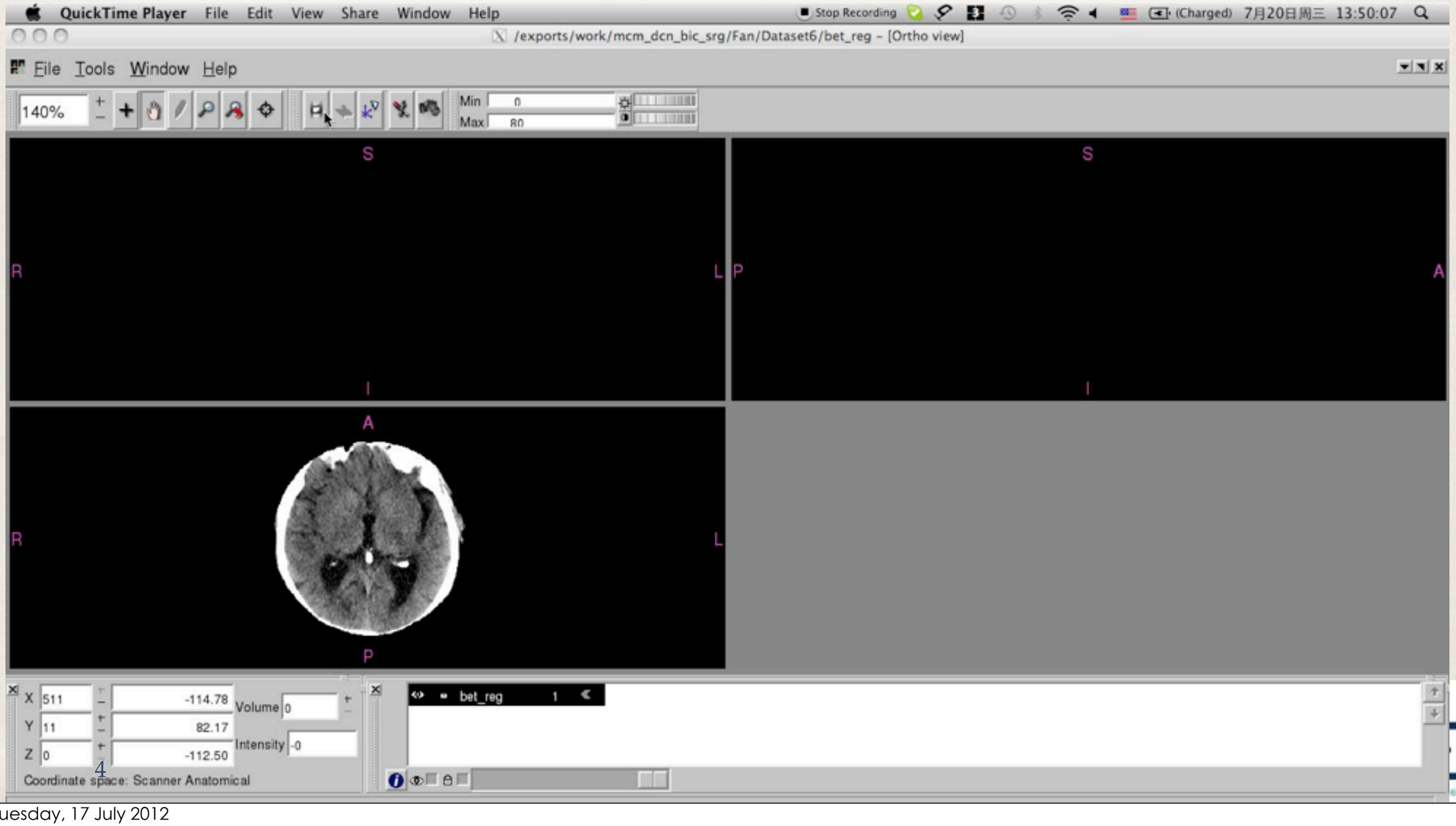


Mean Transmit Time



Perfusion Imaging Overview

Perfusion Imaging Overview



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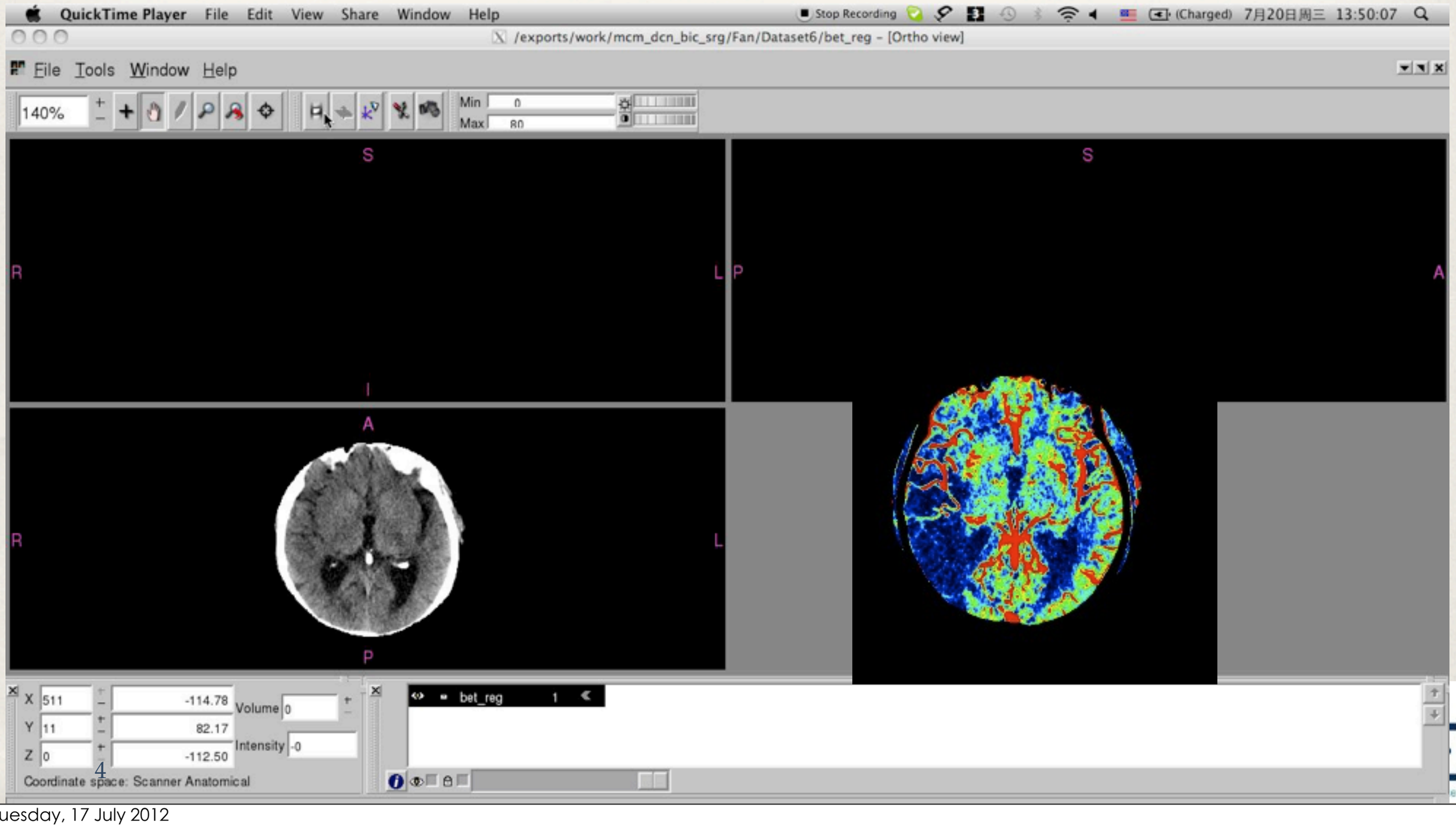

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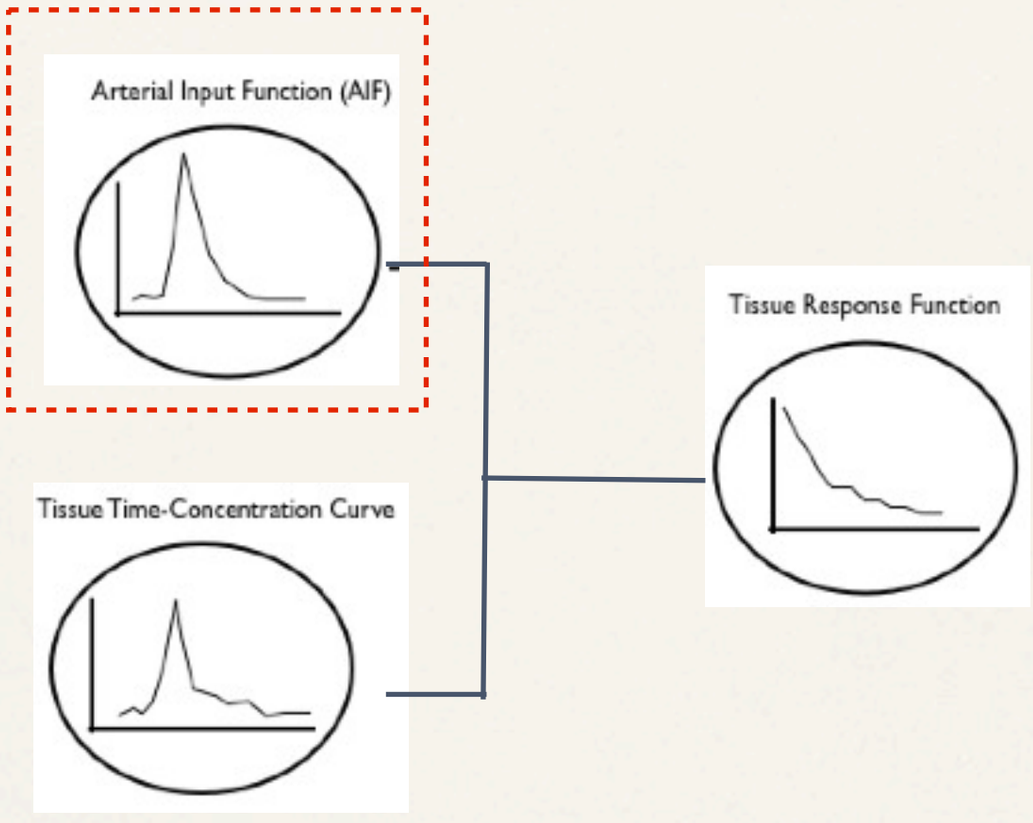
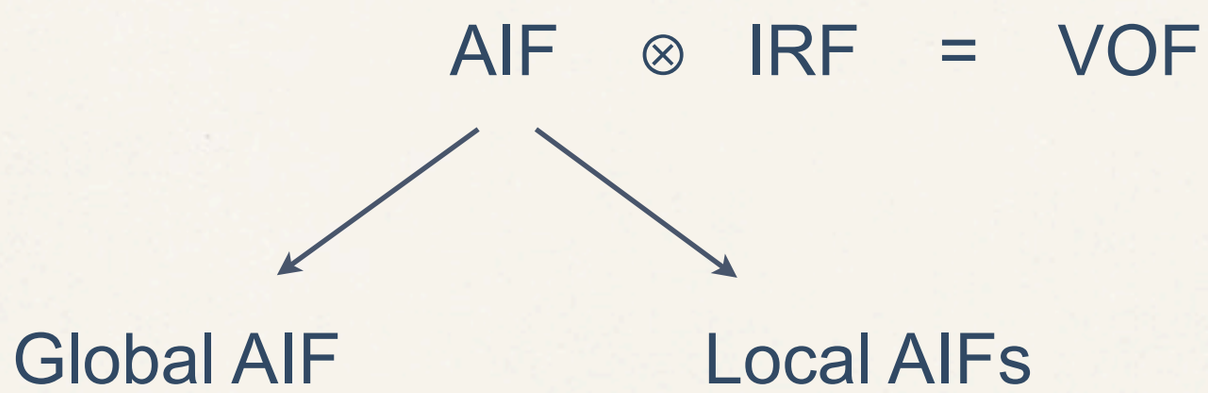
- Perfusion Imaging Introduction
- Performance in Perfusion Imaging Processing
- Noise Reduction in Perfusion Imaging using Gaussian process regression

Arterial Input Function



Local (Arterial Input Function) AIFs



Local (Arterial Input Function) AIFs

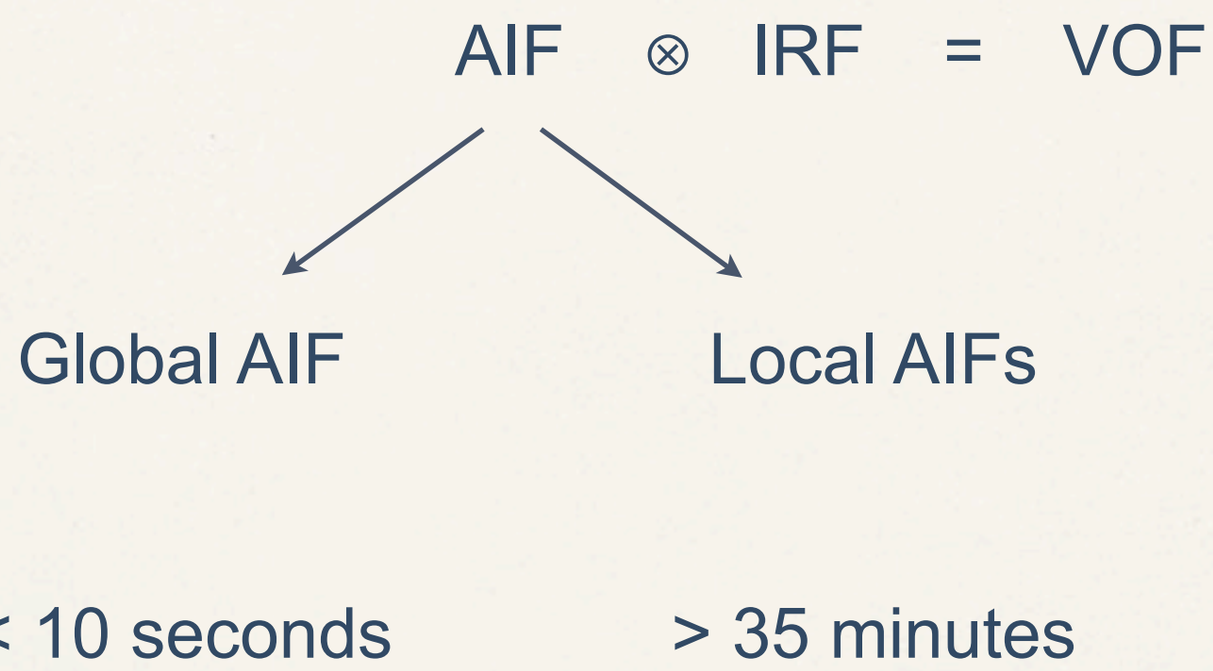
AIF ⊗ IRF = VOF

Global AIF

Local AIFs

< 10 seconds

Local (Arterial Input Function) AIFs



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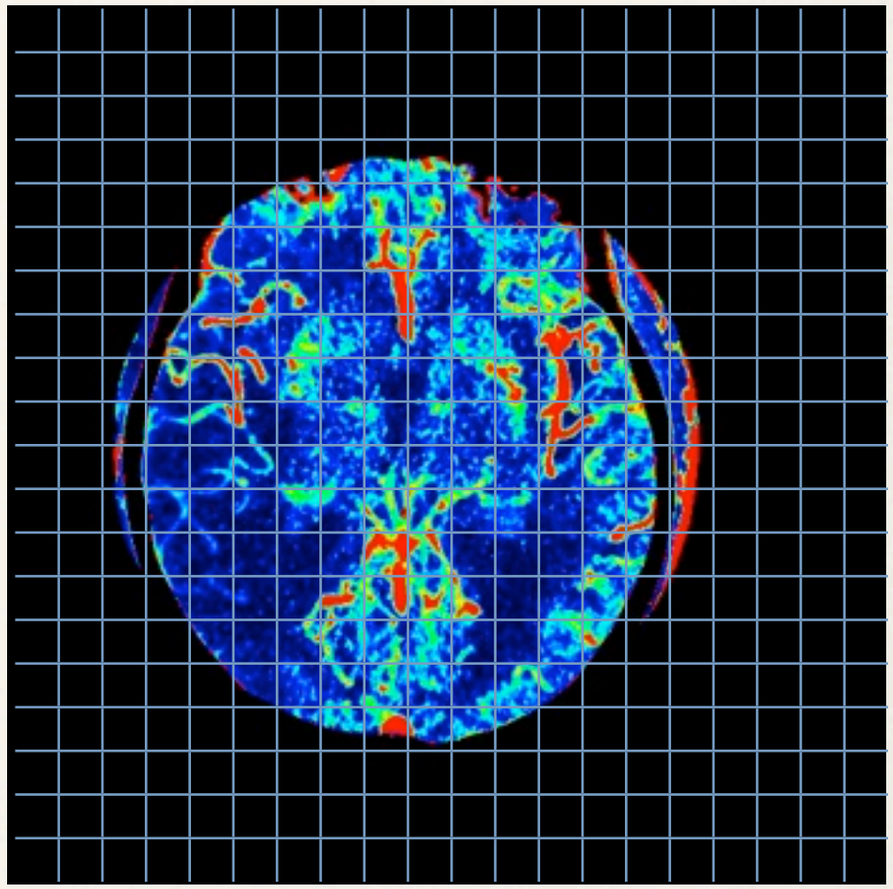
How Parallelization Works



- Tens of Thousands of voxels
  - Ideally Parallel when deconvolution using data parallelism

General Purpose Computing on Graphics Processing Units (GPGPU)

- Similar to multicore CPU
  - Weak cores.
  - Much higher number of cores
- CUDA by NVIDIA
  - C extension

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Performance with local AIFs

Data Size ($Dim1 \times Dim2 \times Dim3 \times time$)	Serial Running Time (s)	GPGPU Running Time (s)	OpenMP Running Time (s)	MPI Running Time (s)
$128 \times 128 \times 22 \times 80$ (MRI Image Size)	2114	564 Speedup Factor = 3.75	956 Speedup Factor = 2.21	619 Speedup Factor = 3.42
$128 \times 128 \times 11 \times 44$ (CT Image Size)	360	65 Speedup Factor = 5.56	159 Speedup Factor = 2.26	94 Speedup Factor = 3.84

One Tesla C1060 GPU

- 240 GPU cores
- 1.44 GHz each core
- 1.0 GB global memory
- 4 KB shared memory
- 1.036 TFLOPS

Two Intel(R) Xeon(R) E5620 CPUs

- Dual cores each
- 3.0 GHz each core
- 8.0 GB global memory
- 4 MB cache each

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The Need for Denoising

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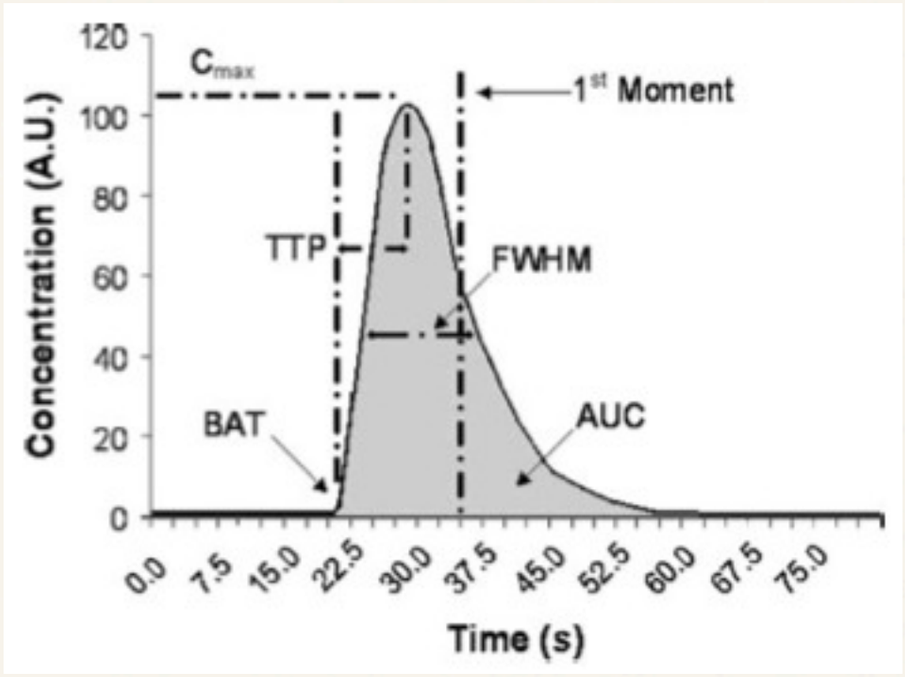

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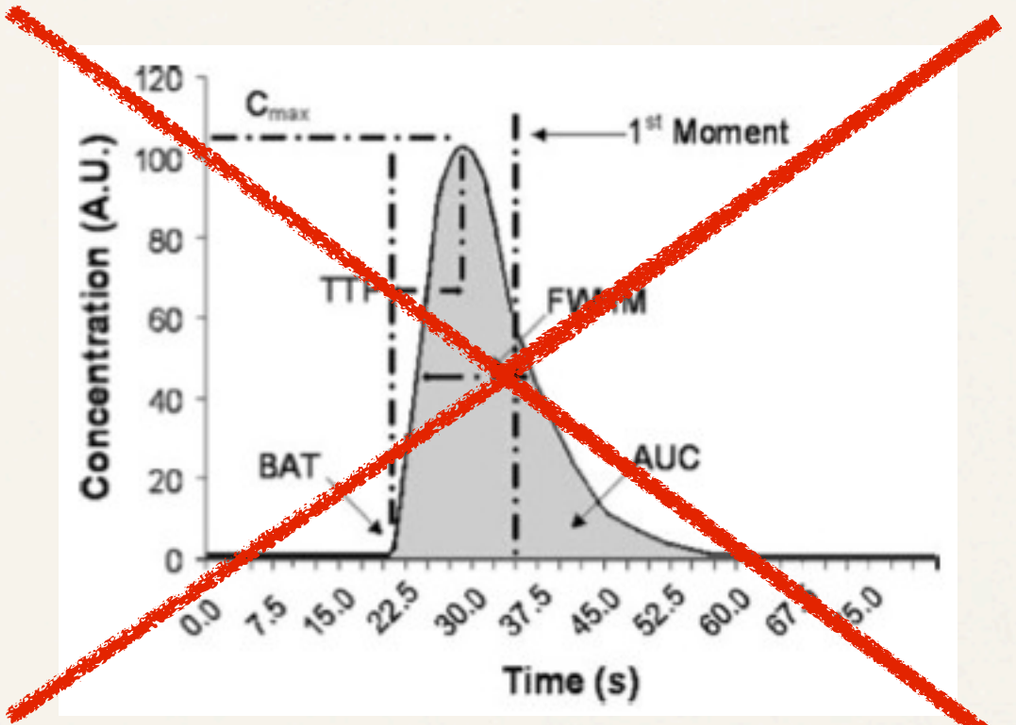

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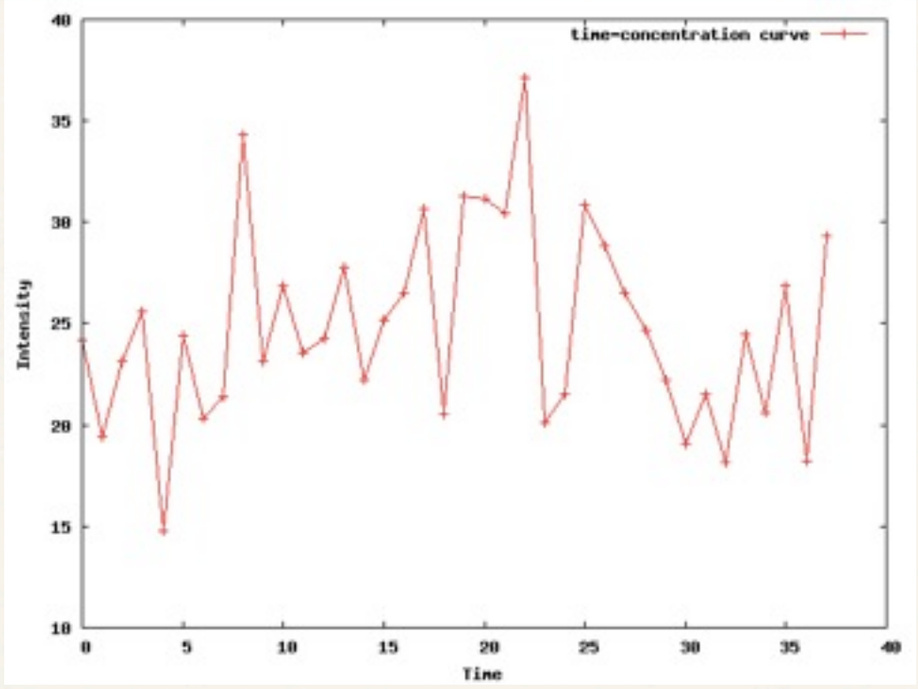

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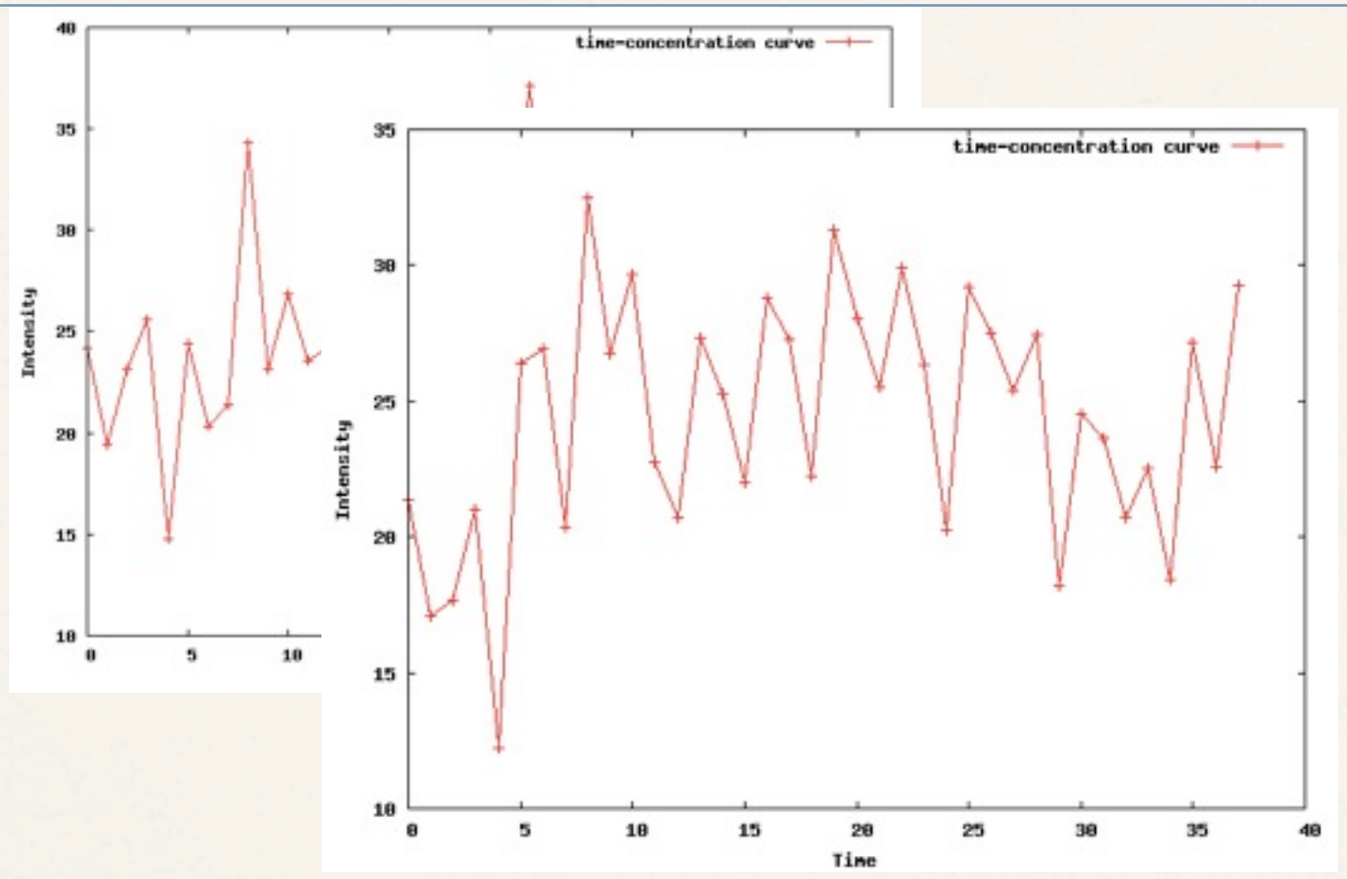

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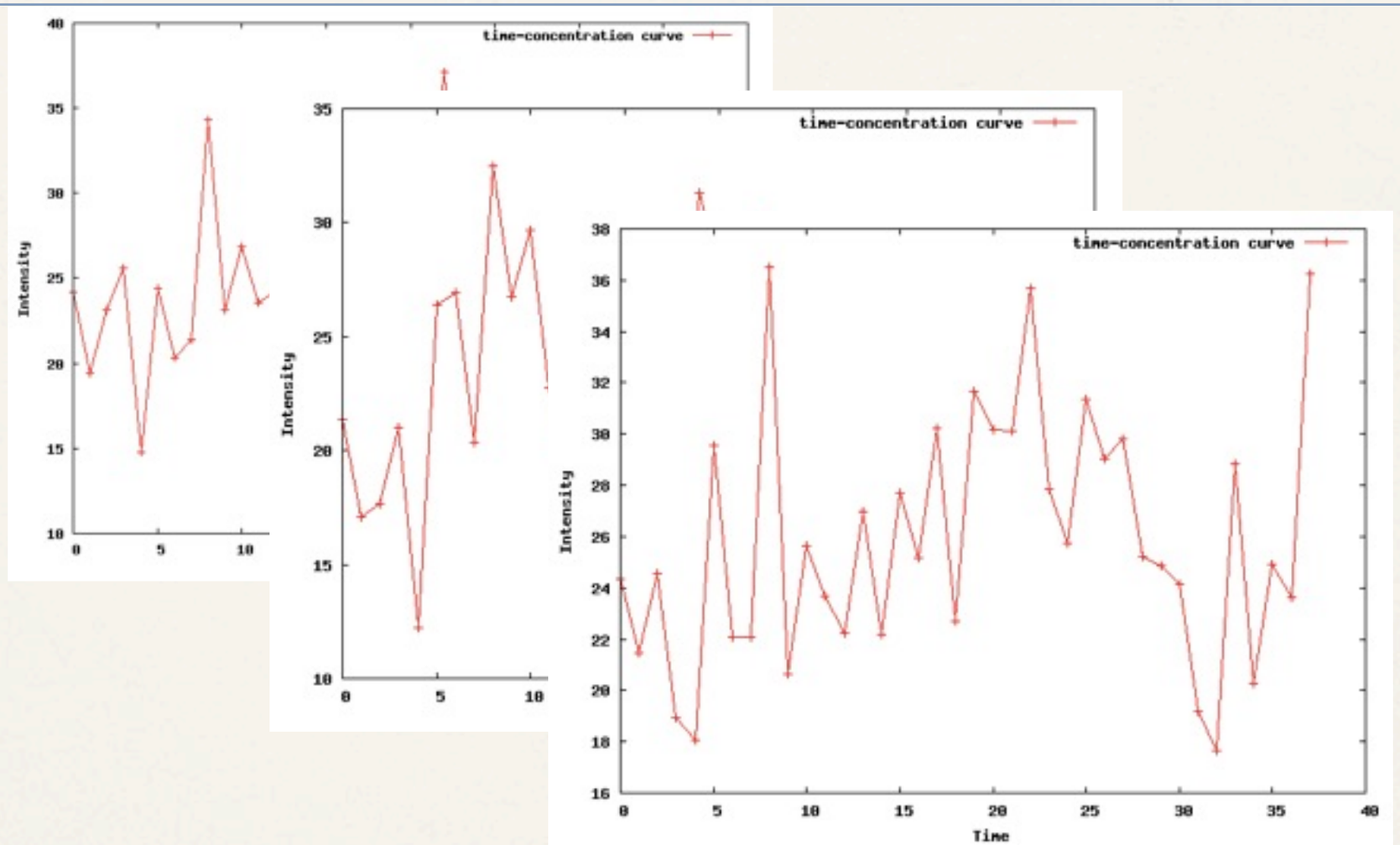
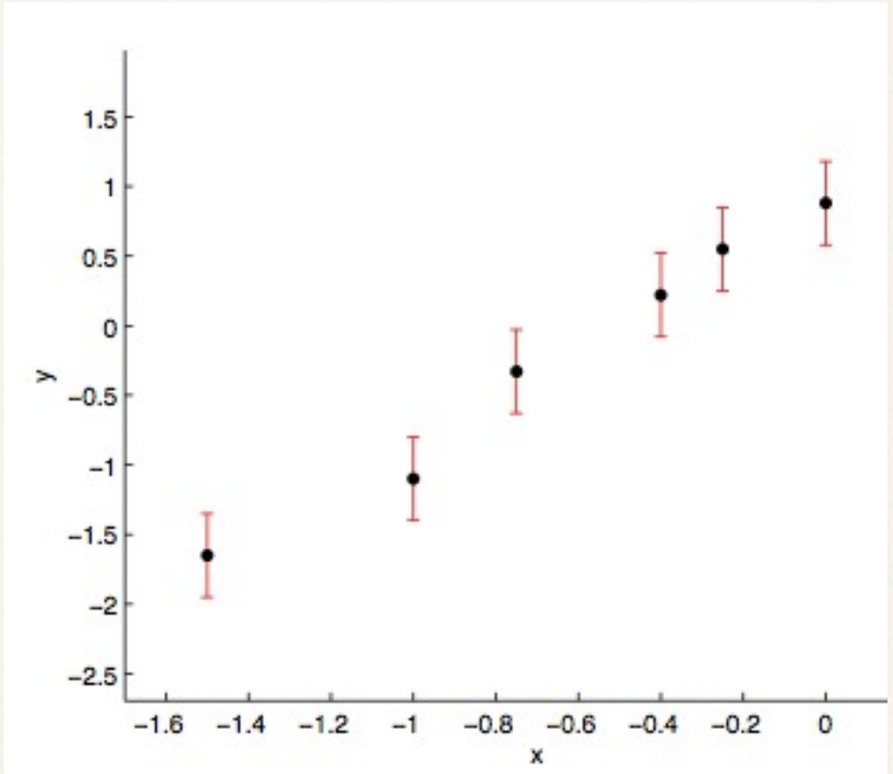


What Gaussian Process Regression Can Do?



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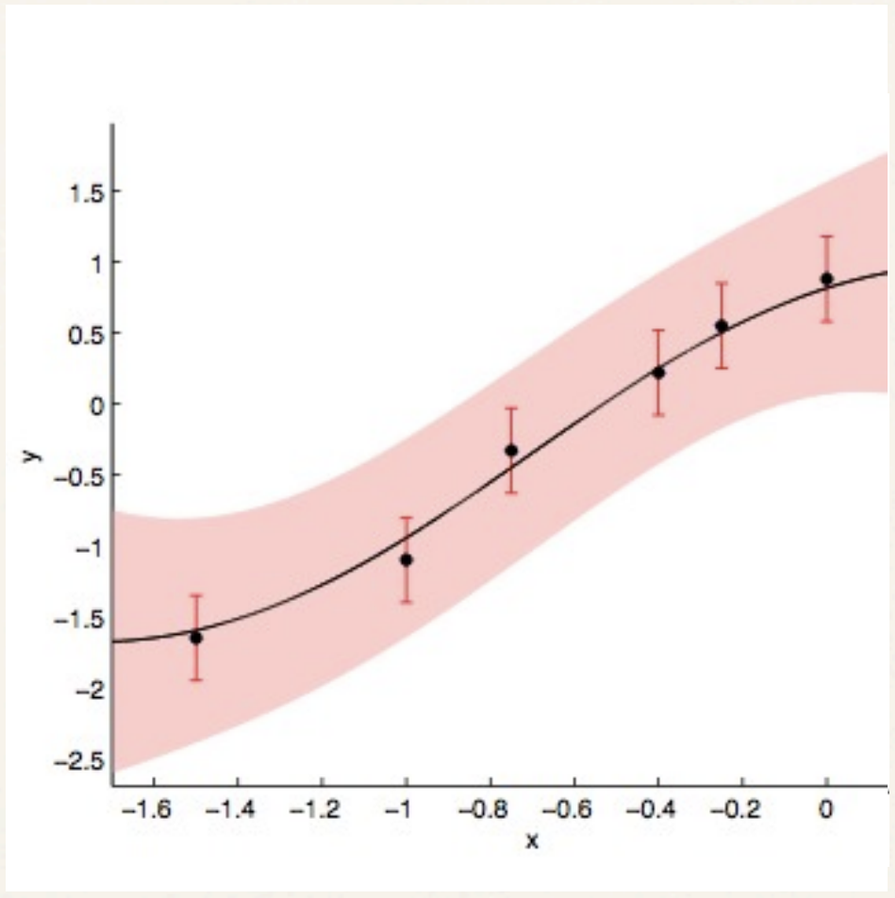


Filter Equation

$$k(t_p,t_q) = \mu_f^2 exp(-\frac{1}{2l^2}(t_p - t_q)^2) + \mu_n^2 \delta_{pq}$$

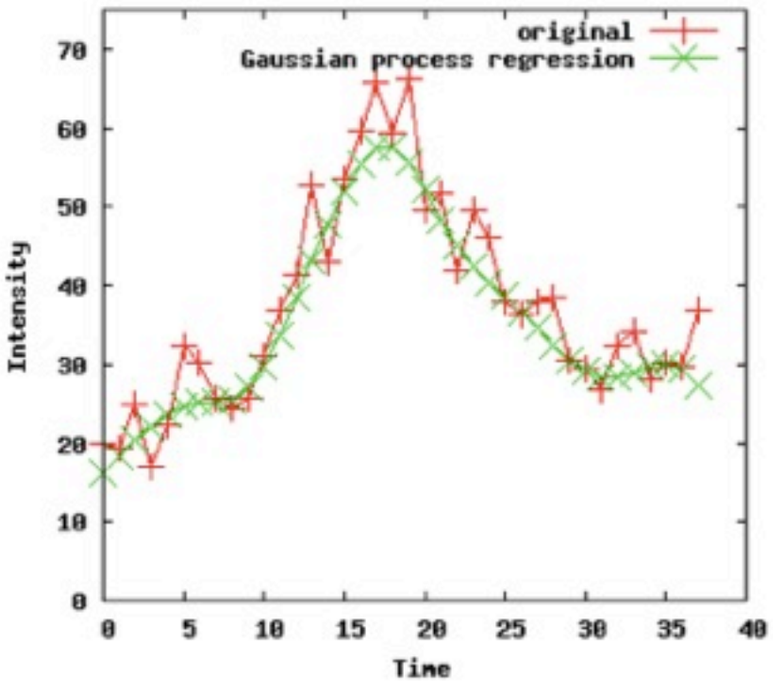
$$K(T,T) = \begin{bmatrix} k(t_1,t_1) & k(t_1,t_2) & \cdots & k(t_1,t_n) \\ k(t_2,t_1) & k(t_2,t_2) & \cdots & k(t_2,t_n) \\ \vdots & \vdots & \ddots & \vdots \\ k(t_n,t_1) & k(t_n,t_2) & \cdots & k(t_n,t_n) \end{bmatrix}$$

$$K(T_*,T) = \begin{bmatrix} k(t_*,t_1) & k(t_*,t_2) & \cdots & k(t_*,t_n) \end{bmatrix}$$

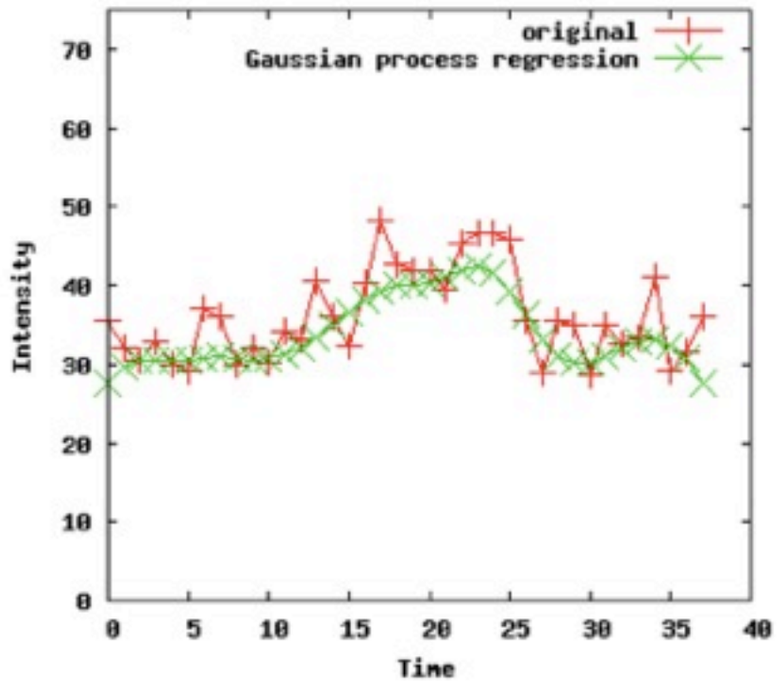
$$K(T_*,T_*) = [k(t_*,t_*)]$$

$$f'(t_x) = [\, k(t_x,t_1) \;\; k(t_x,t_2) \;\; \cdots \;\; k(t_x,t_n) \,] \begin{bmatrix} k(t_1,t_1) & k(t_1,t_2) & \cdots & k(t_1,t_n) \\ k(t_2,t_1) & k(t_2,t_2) & \cdots & k(t_2,t_n) \\ \vdots & \vdots & \ddots & \vdots \\ k(t_n,t_1) & k(t_n,t_2) & \cdots & k(t_n,t_n) \end{bmatrix}^{-1} \begin{bmatrix} f(t_1) \\ f(t_2) \\ \vdots \\ f(t_n) \end{bmatrix}$$

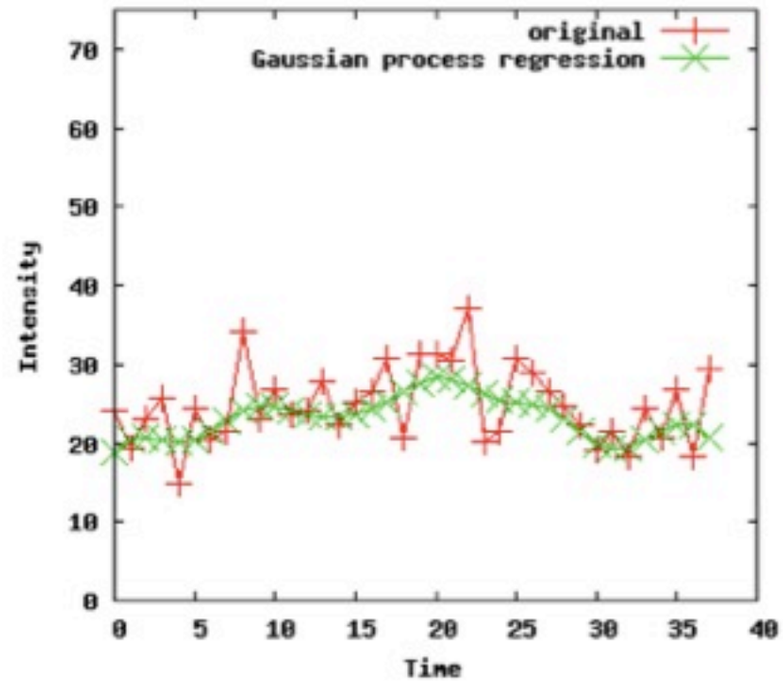
Result of Using GPR



(a) Artery

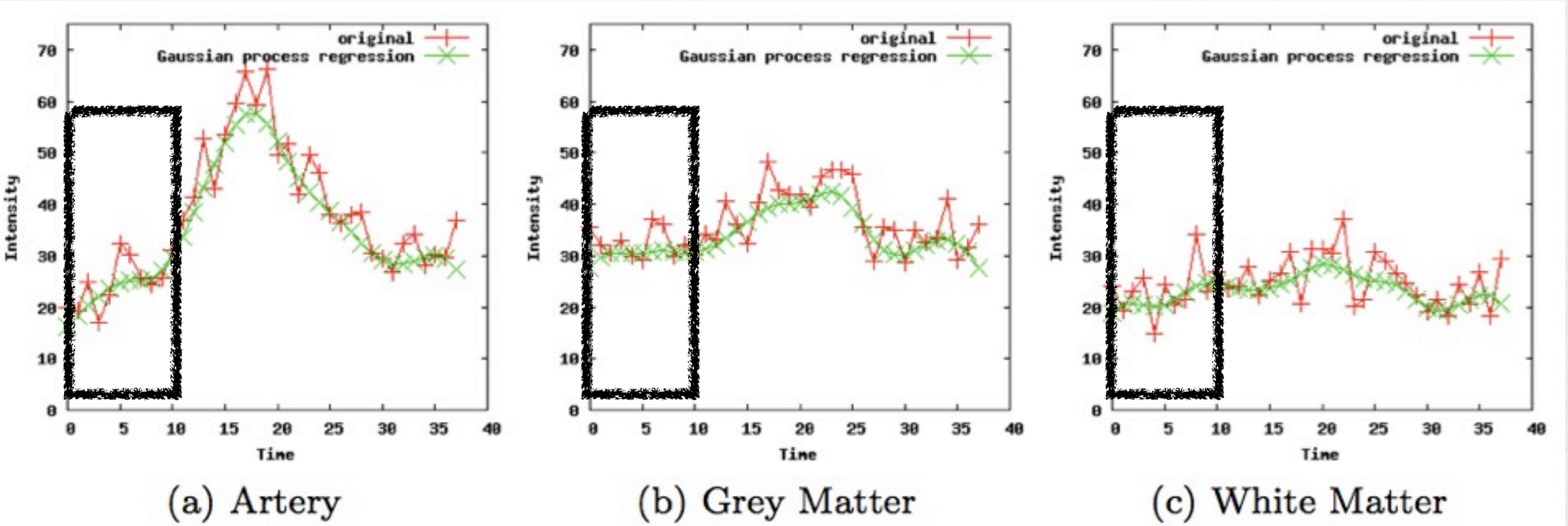


(b) Grey Matter



(c) White Matter

Result of Using GPR



(a) Artery (b) Grey Matter (c) White Matter

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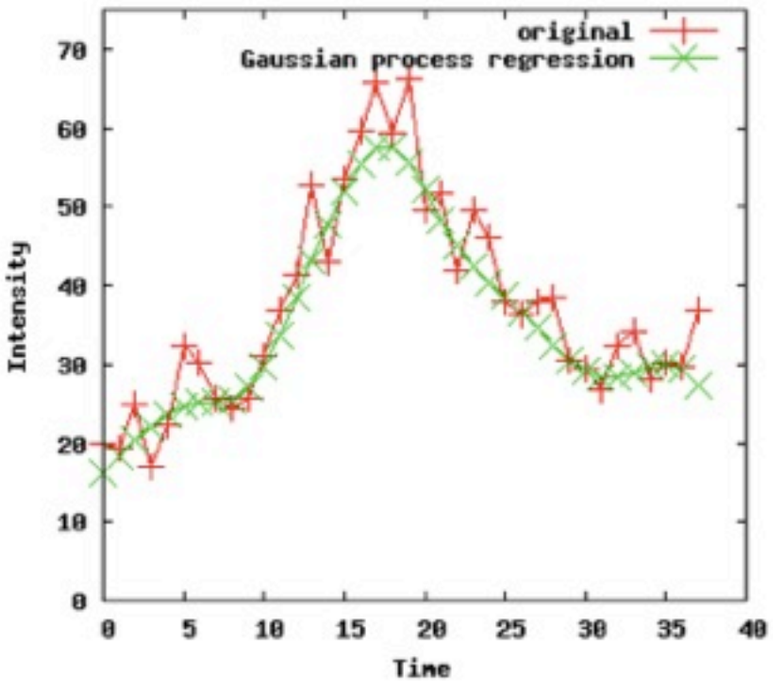

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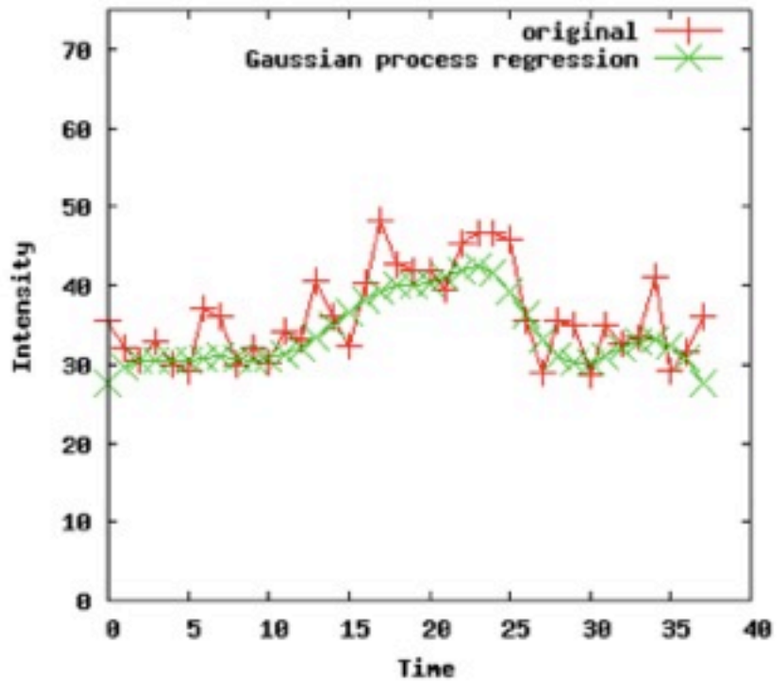

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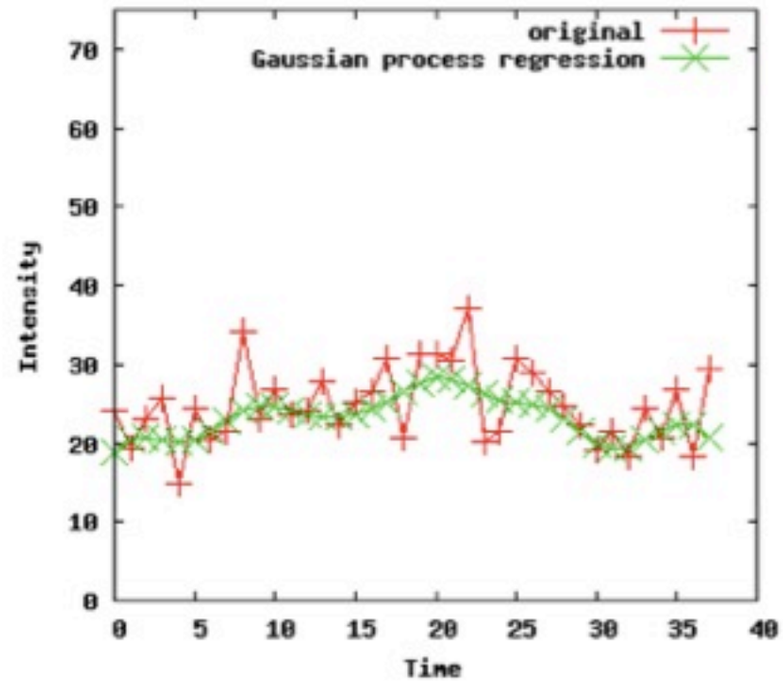

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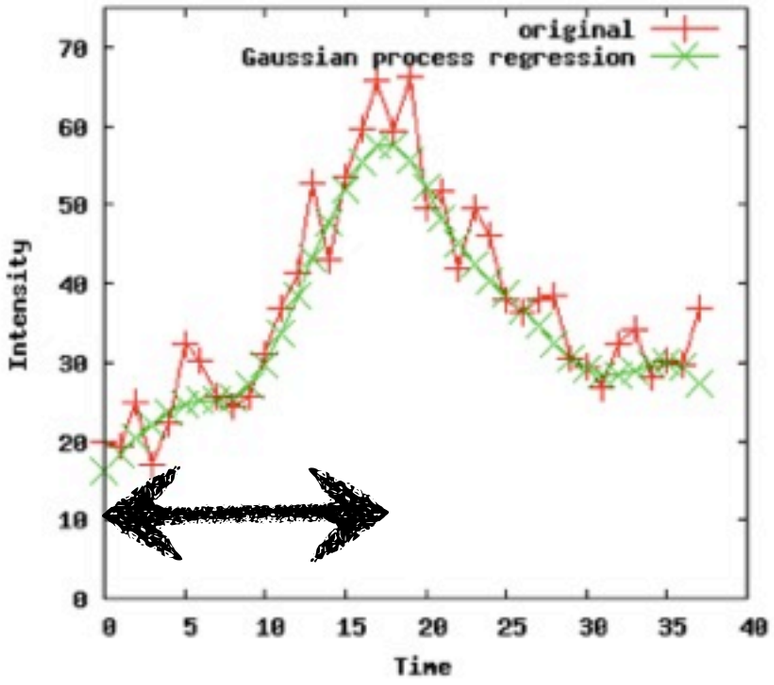

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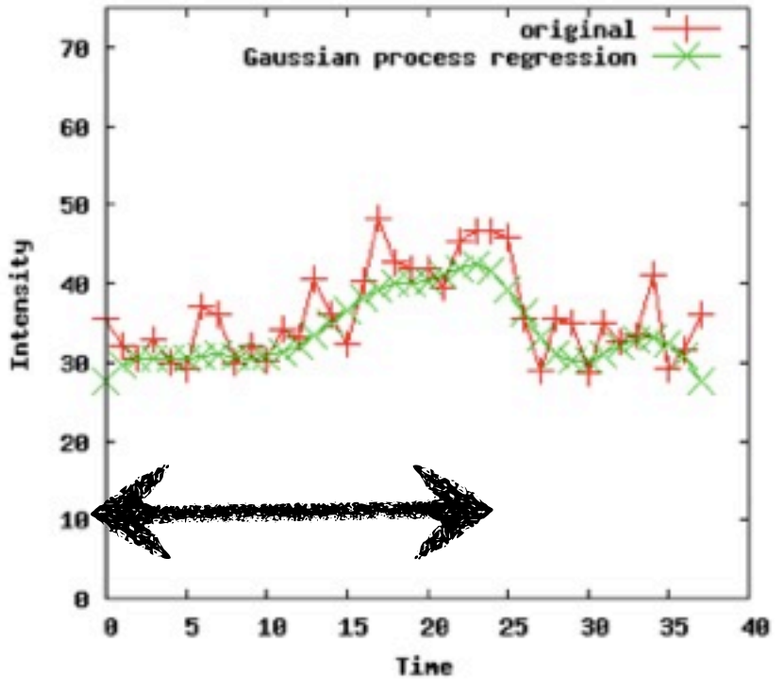
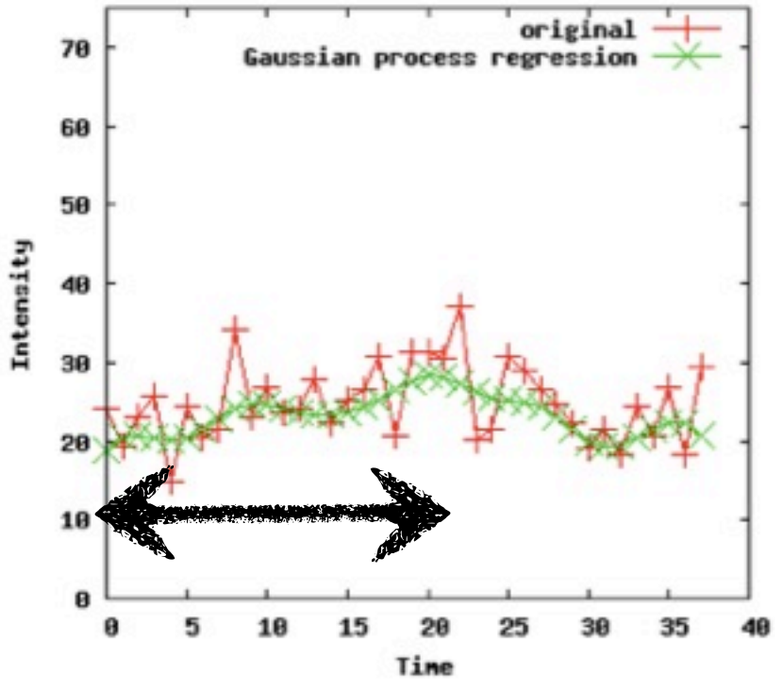


(b) Grey Matter



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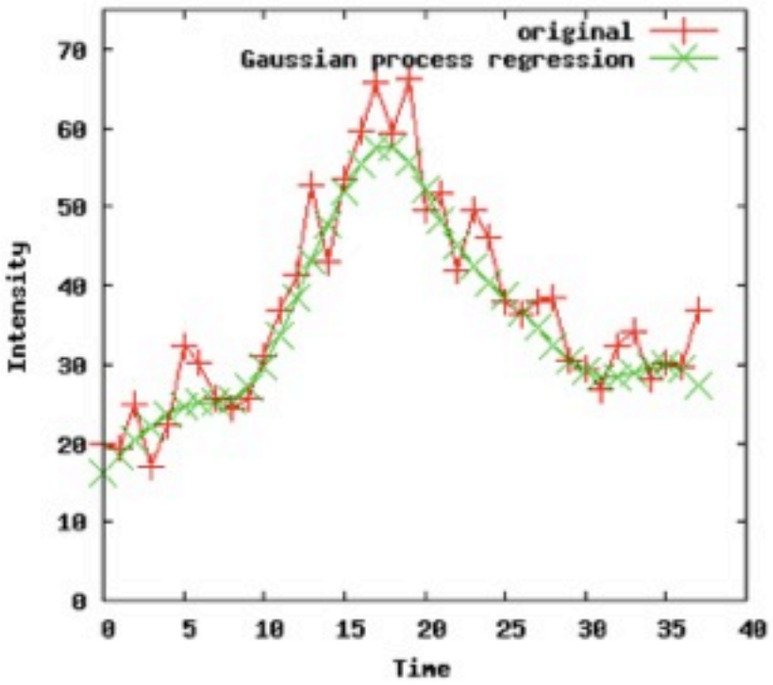
Result of Using GPR



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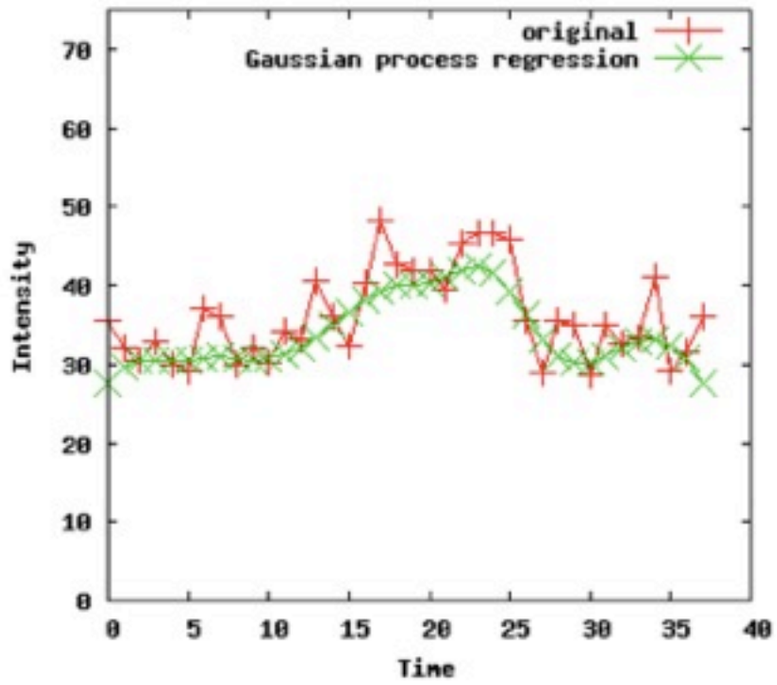

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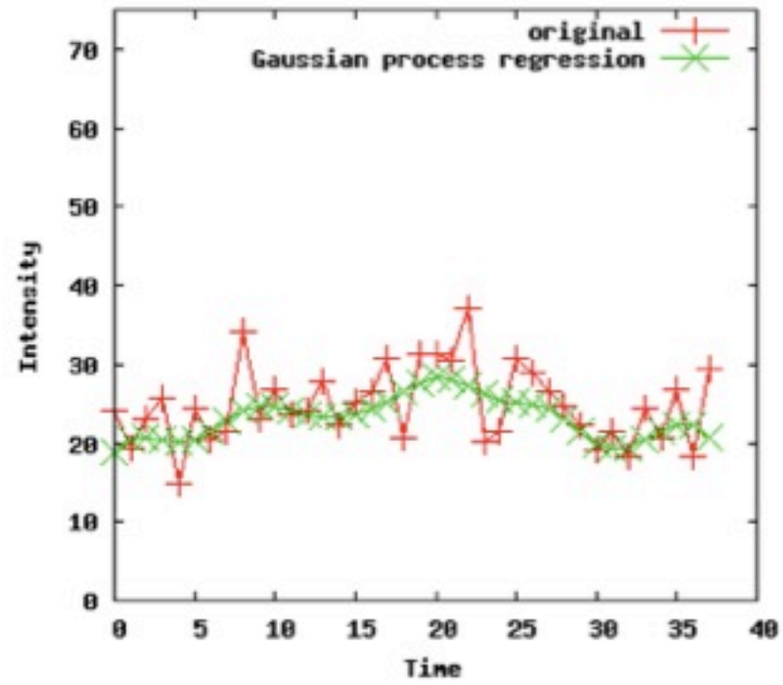

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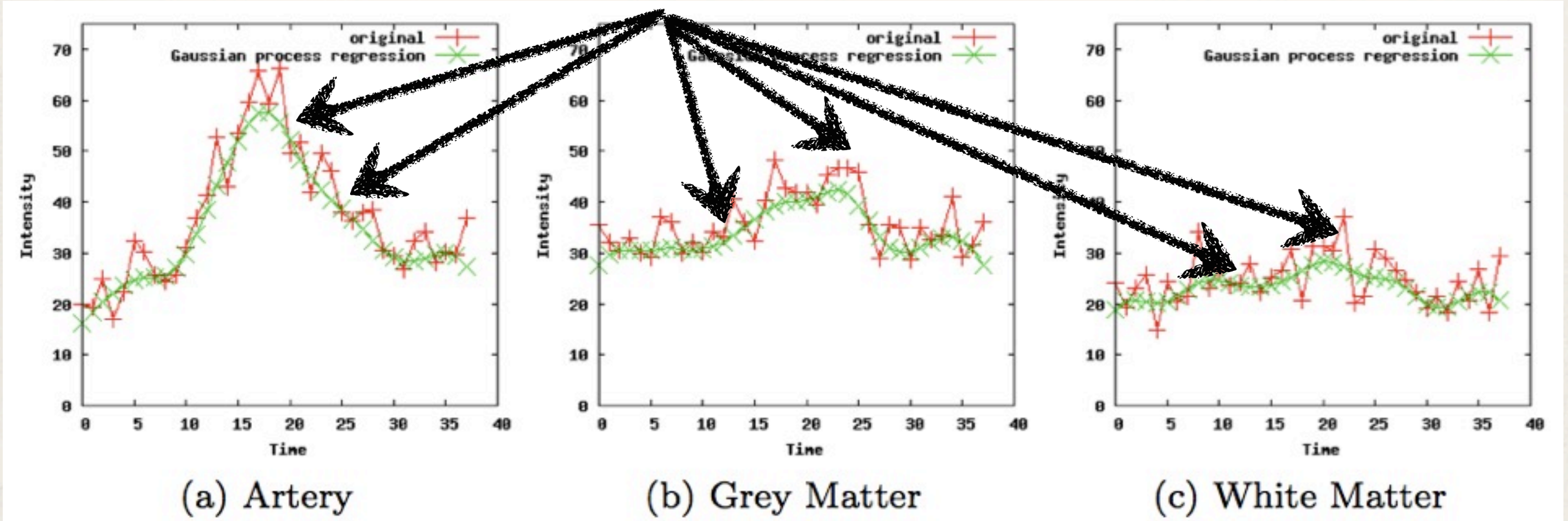


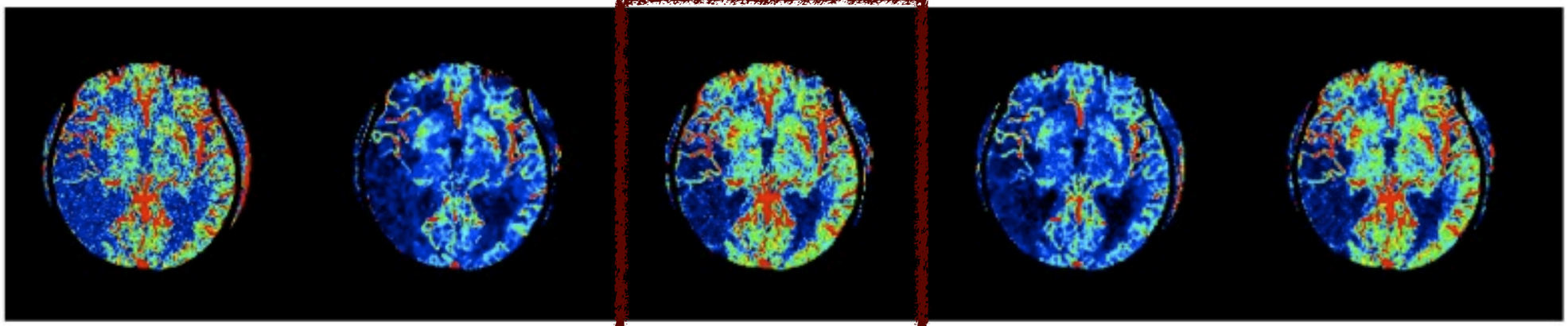
(a) Artery (b) Grey Matter (c) White Matter

Contrast-to-Noise Ratio

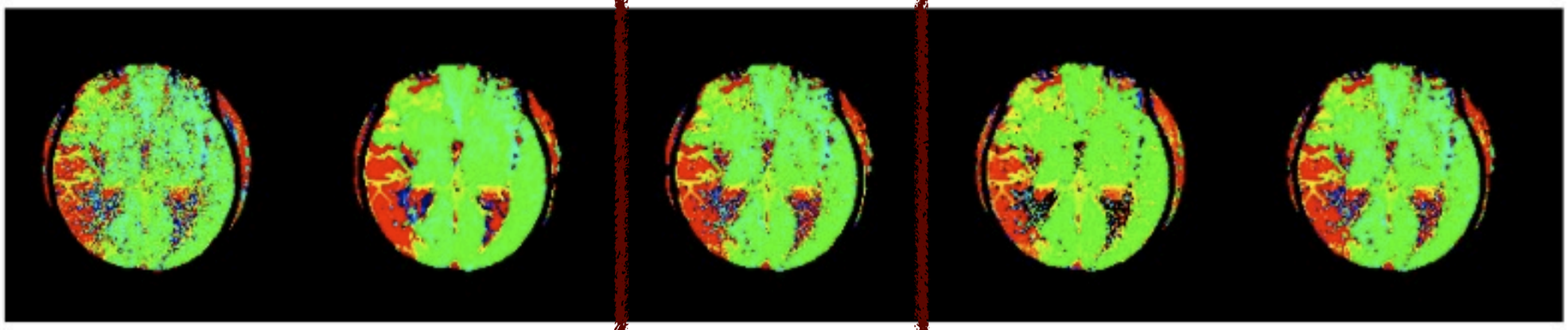
- Similar to SNR

Optimized results	Original	GPR
Mean	1	1.99
Standard Deviation	-	0.516

Parametric Maps

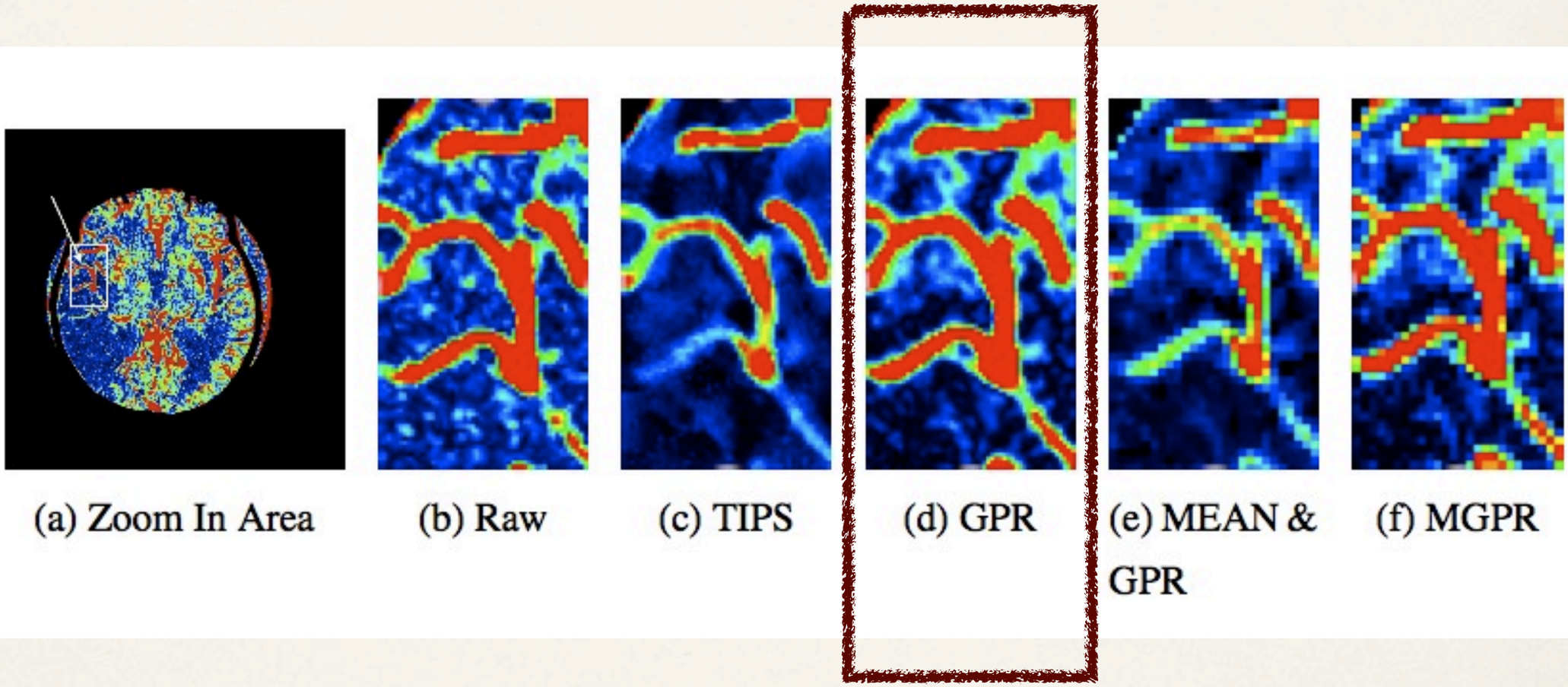


(a) Raw CBF (b) TIPS CBF (c) GPR CBF (d) MEAN & GPR CBF (e) MGPR CBF



(f) Raw TTP (g) TIPS TTP (h) GPR TTP (i) MEAN & GPR TTP (j) MGPR TTP

Parametric Maps (con.)



(a) Zoom In Area (b) Raw (c) TIPS (d) GPR (e) MEAN & GPR (f) MGPR

Conclusion

- Performance speedup
  - Speedup factor 4 - 5.5
- Noise reduction
  - Improve CNR by 0.99
-

Thank you.