Multiple Model Predictive Control of Hemodynamic Variables

An Experimental Study

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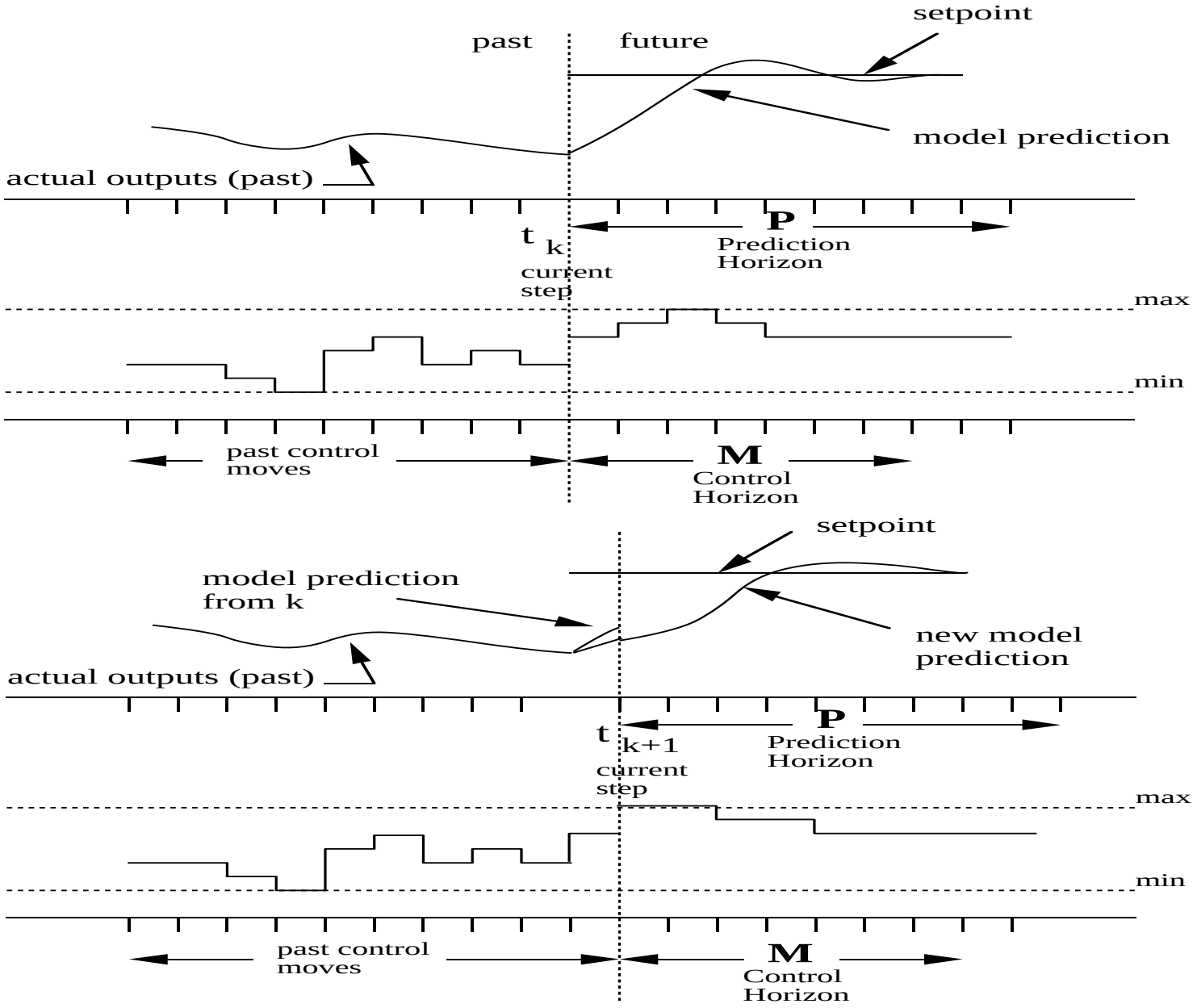
Motivation

- Patients in critical care or surgery
- Typical clinical practice
  - manual regulation with drip IV
  - programmable pumps (open loop)
  - estimation of pharmacokinetics and pharmacodynamics
- State of the art
  - clinical trials of closed loop control of mean arterial pressure (MAP)
- Our objective
  - automated regulation of hemodynamic variables with physician ”in the loop”
  - free-up physician to monitor difficult-to-measure variables

Problem Overview

- Multivariable, nonlinear system
  - regulation of mean arterial pressure (MAP), cardiac output (CO) using sodium nitroprusside (SNP), phenylephrine (PNP) and dopamine (DPM)
- Inter- and intra patient variability
  - requires on-line adaptation to patient conditions
- Interactions from anesthetics
- Presence of constraint specifications
  - inputs: drug dosage
  - outputs: setpoint specified as range, min or max
- Use model predictive control (MPC) to handle constraints explicitly



Model Predictive Control

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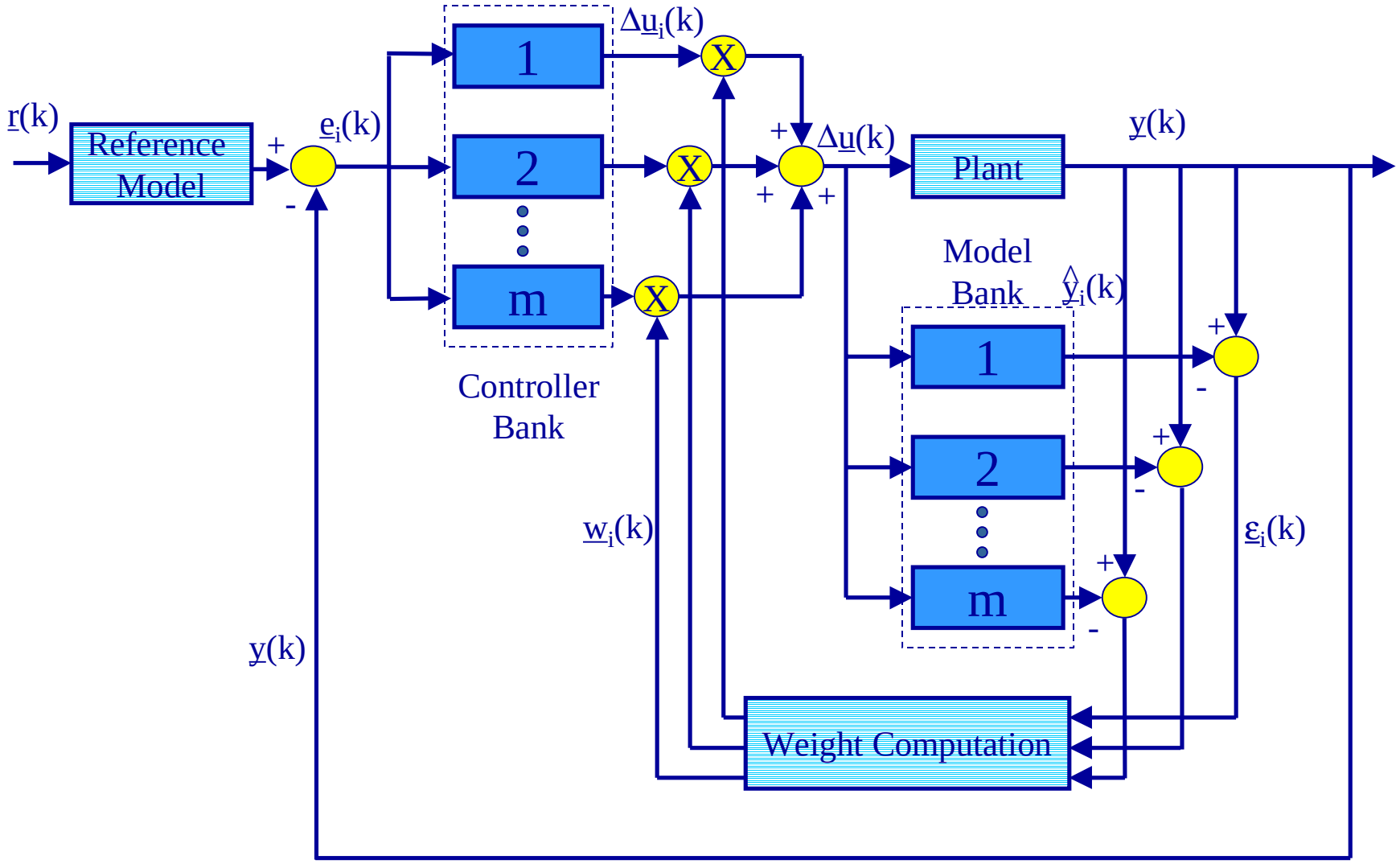
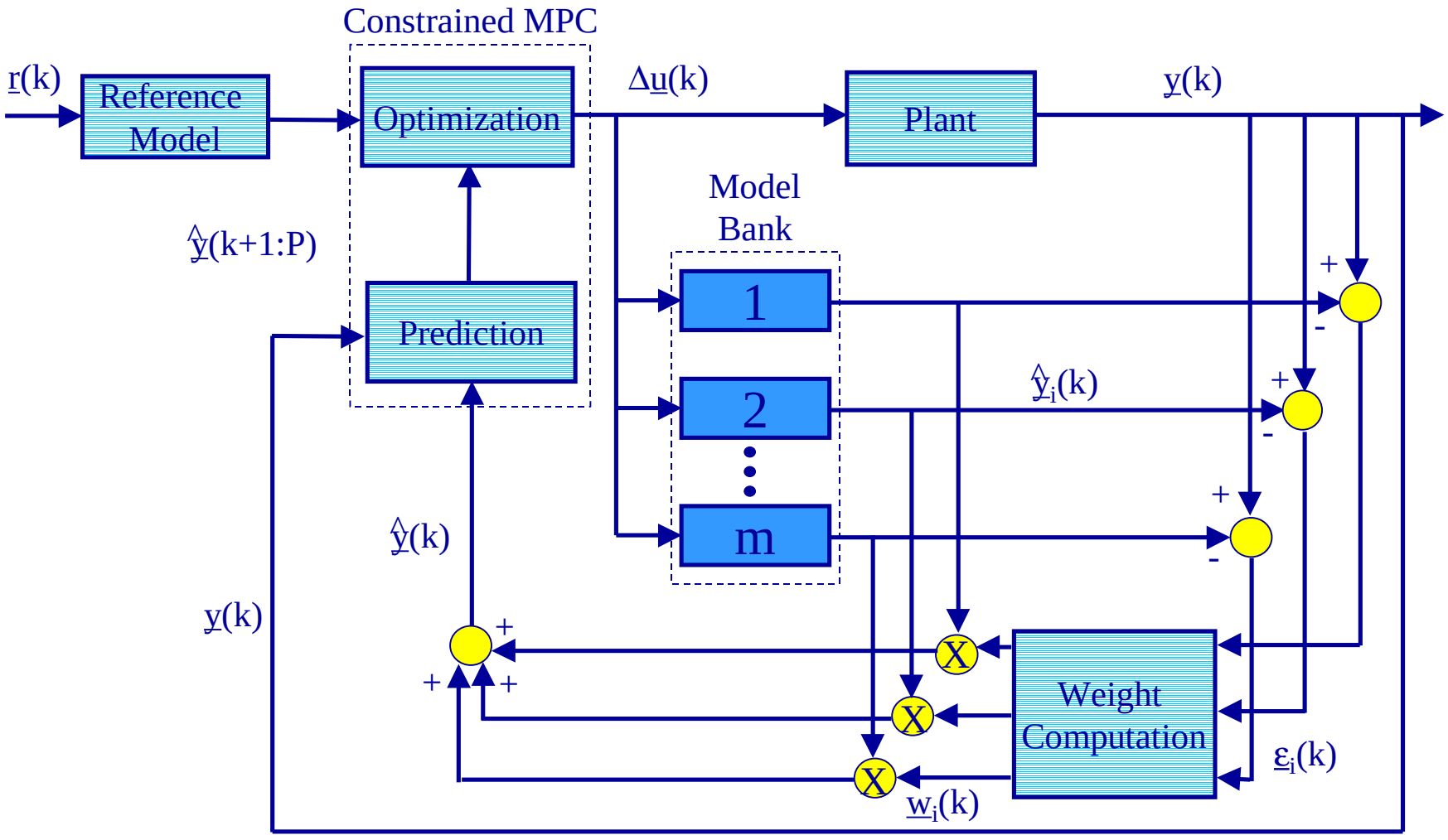
Multiple Model Adaptive Control (MMAC)



Multiple Model Predictive Control (MMPC)



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Weighting Scheme

Recursive Bayes Conditional Probability

$$p_{i,k} = \frac{\exp(-\frac{1}{2}\varepsilon_{i,k}^{T} K \varepsilon_{i,k}) p_{i,k-1}}{\sum_{j=1}^{N} [\exp(-\frac{1}{2}\varepsilon_{j,k}^{T} K \varepsilon_{j,k}) p_{j,k-1}]}$$

Weights

$$W_{i,k} = \frac{P_{i,k}}{\sum_{j=1}^{N} P_{j,k}} \quad \text{for} \quad P_{i,k} > \delta$$

$$W_{i,k} = 0 \quad \text{for} \quad P_{i,k} = \delta$$

- **Probabilities & weights properly bounded**
- **Delta keeps model available for future use**
- **Steady state probabilities are 0 or 1**

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Model banks

	MAP			CO		
	Gain	**Time Constants**	**Time Delays**	**Gain**	**Time Constants**	**Time Delays**
SNP	-5 to -23	1.0 to 1.2	0.5	5 to 30	1 to 1.5	1 to 2
DPM	1 to 10	4 to 6	1 to 3	5 to 50	5 to 6	1 to 3

	MAP			CO		
	Gain	**Time Constants**	**Time Delays**	**Gain**	**Time Constants**	**Time Delays**
SNP	-4 to –35	1.2 to 2.0	.5 to 1.5	-1 to -9	1 to 2	0.5 to 1
DPM	1 to 9	5 to 7	2 to 4	5 to 57	5 to 7	1 to 5

Heart Contractility
↑ Dopamine (Inotropic)
↓ Halothane

Venous Compliance
↓ Sodium Nitroprusside

Baroreceptor Reflex
↓ Halothane

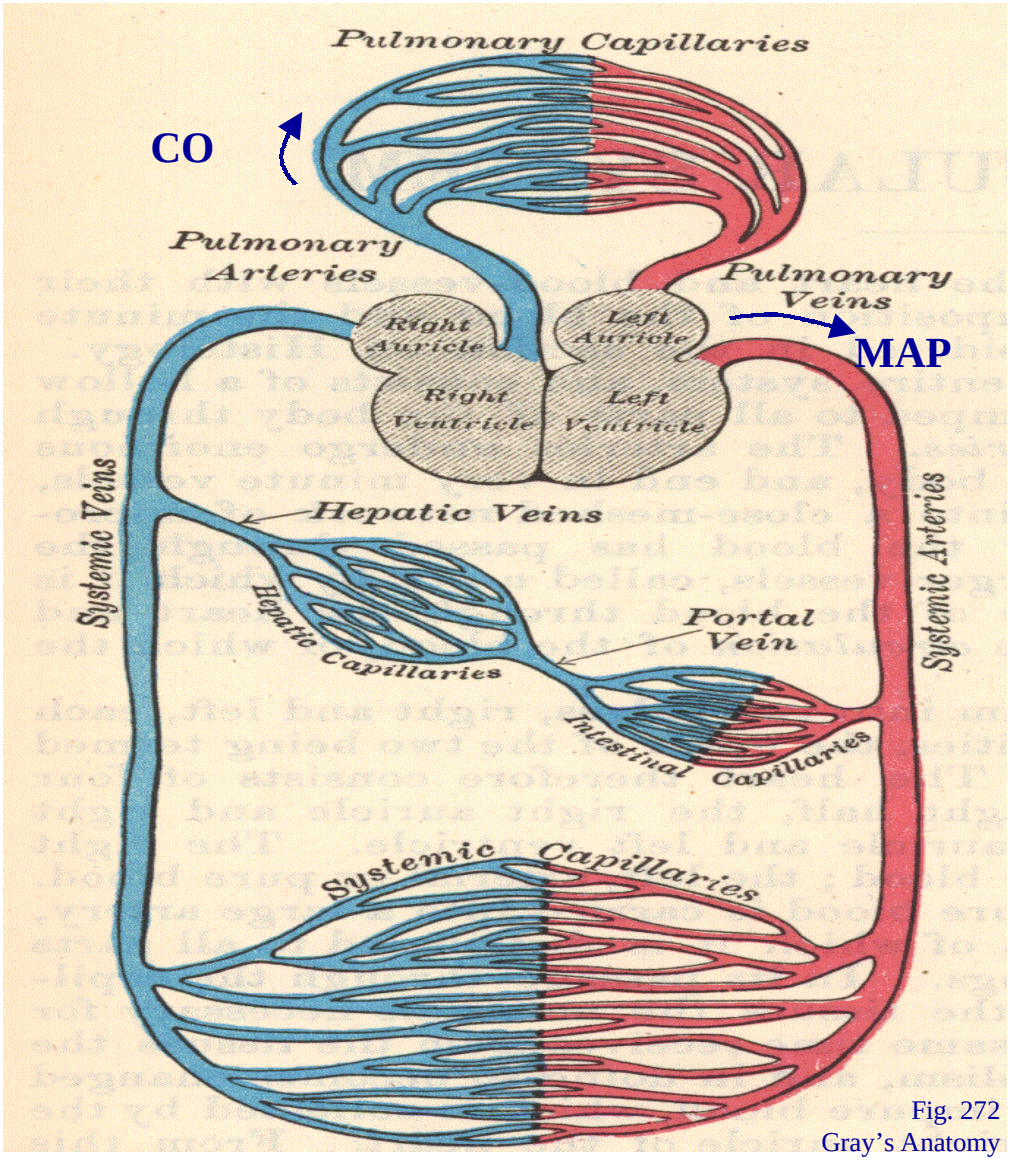

Fig. 272
Gray's Anatomy

Systemic Vascular Resistance
↑ Phenylephrine
↓ Sodium Nitroprusside
↓ Isoflurane
↓ Halothane
↓ Metabolites

MAP-CO Relation
$MAP=CO*(SVR-P_{RA})$

■ Anesthetic
■ Cardiovascular Drugs

Physiological Overview

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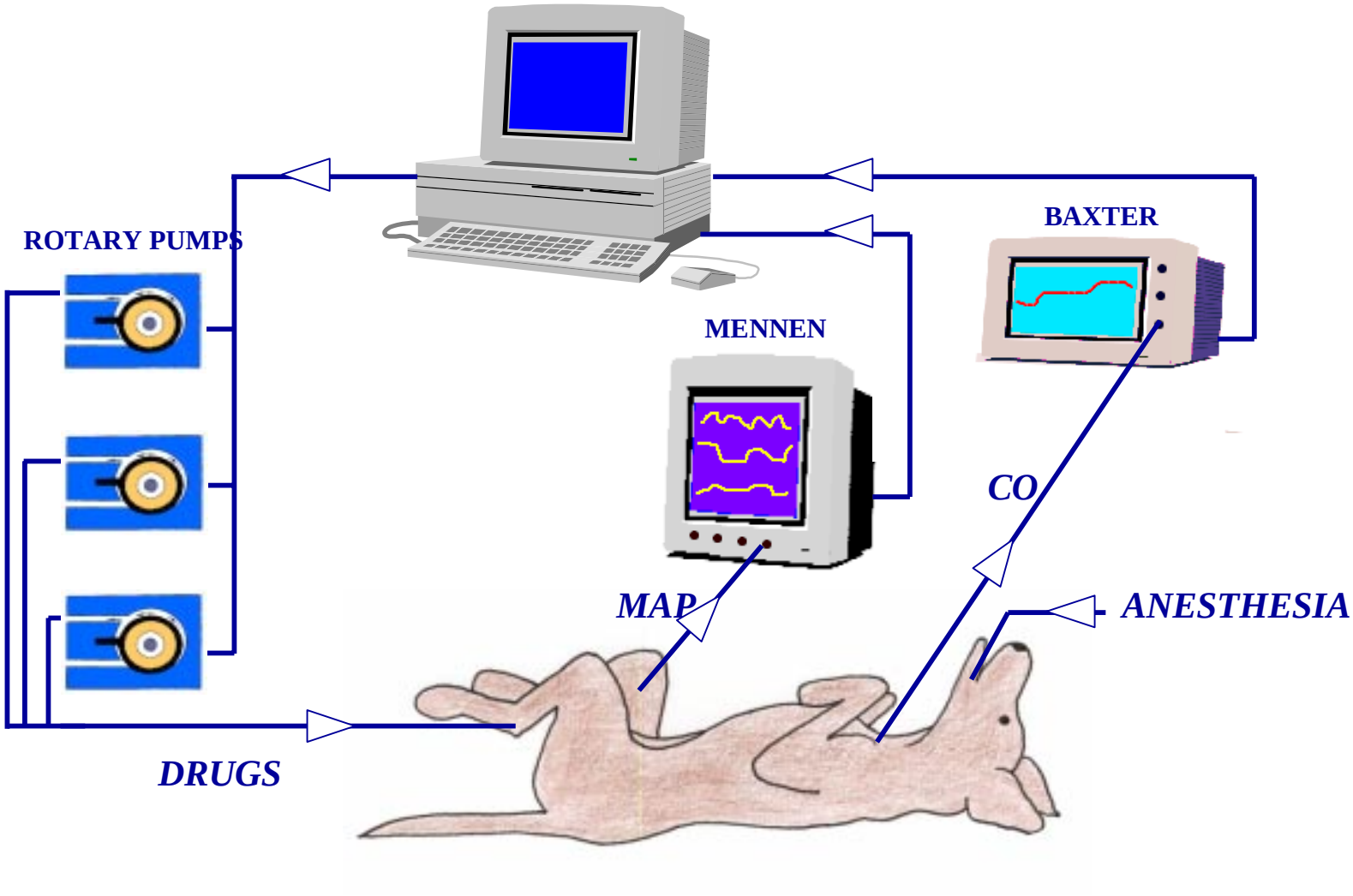
Experimental Setup



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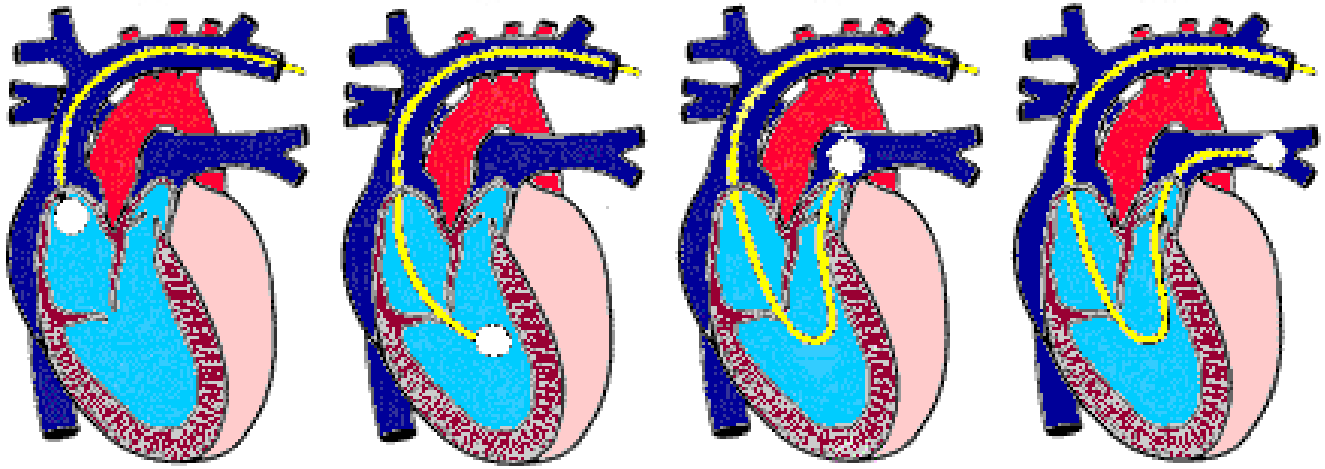
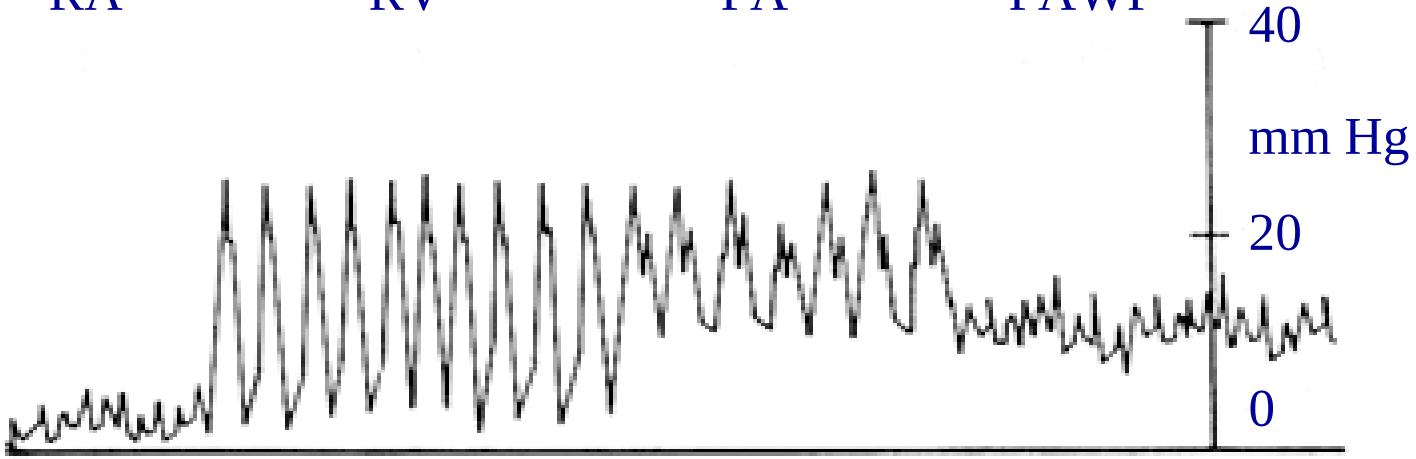


RA RV PA PAWP

EKG



Swan-Ganz Insertion

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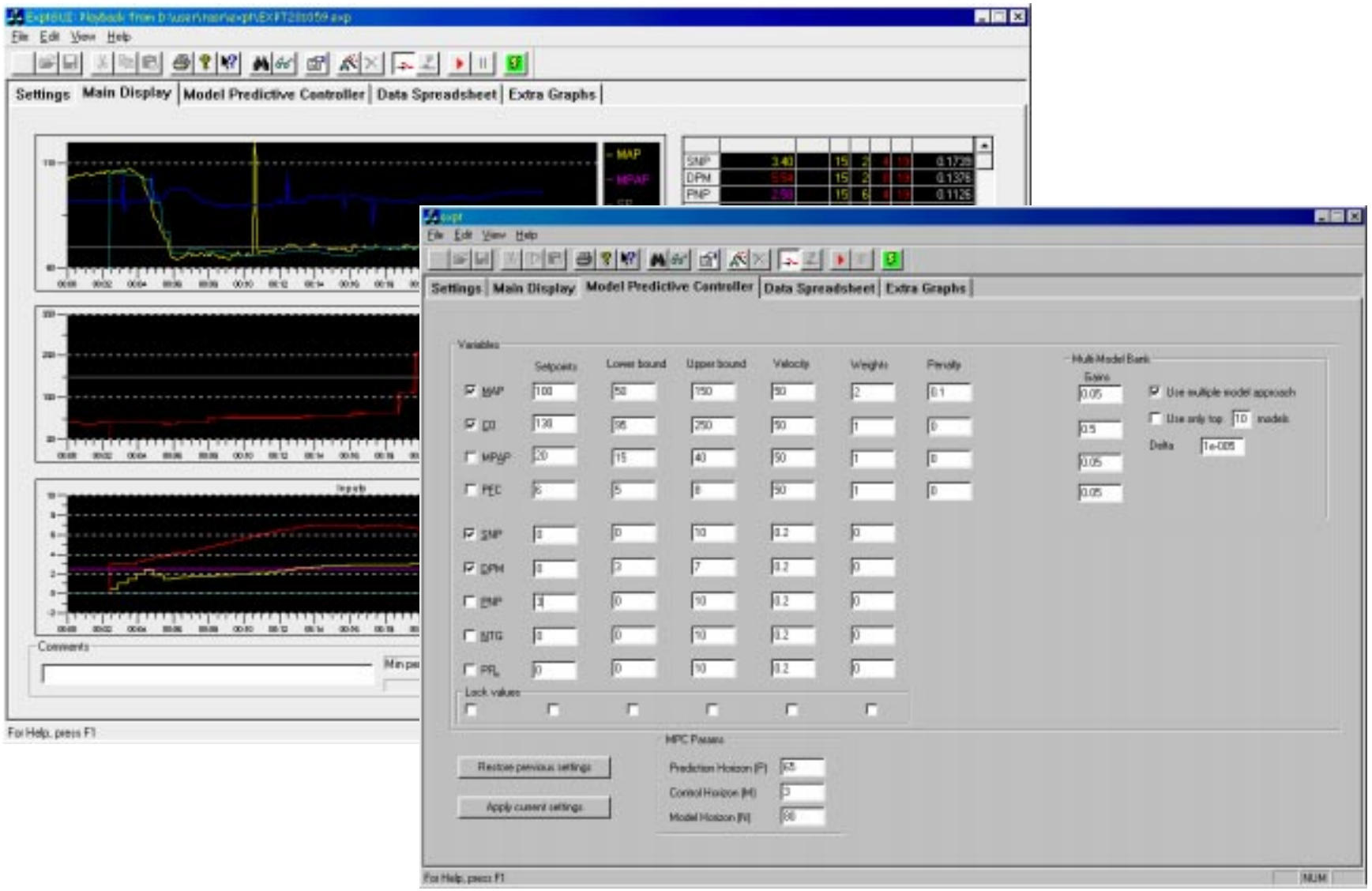
User Interface



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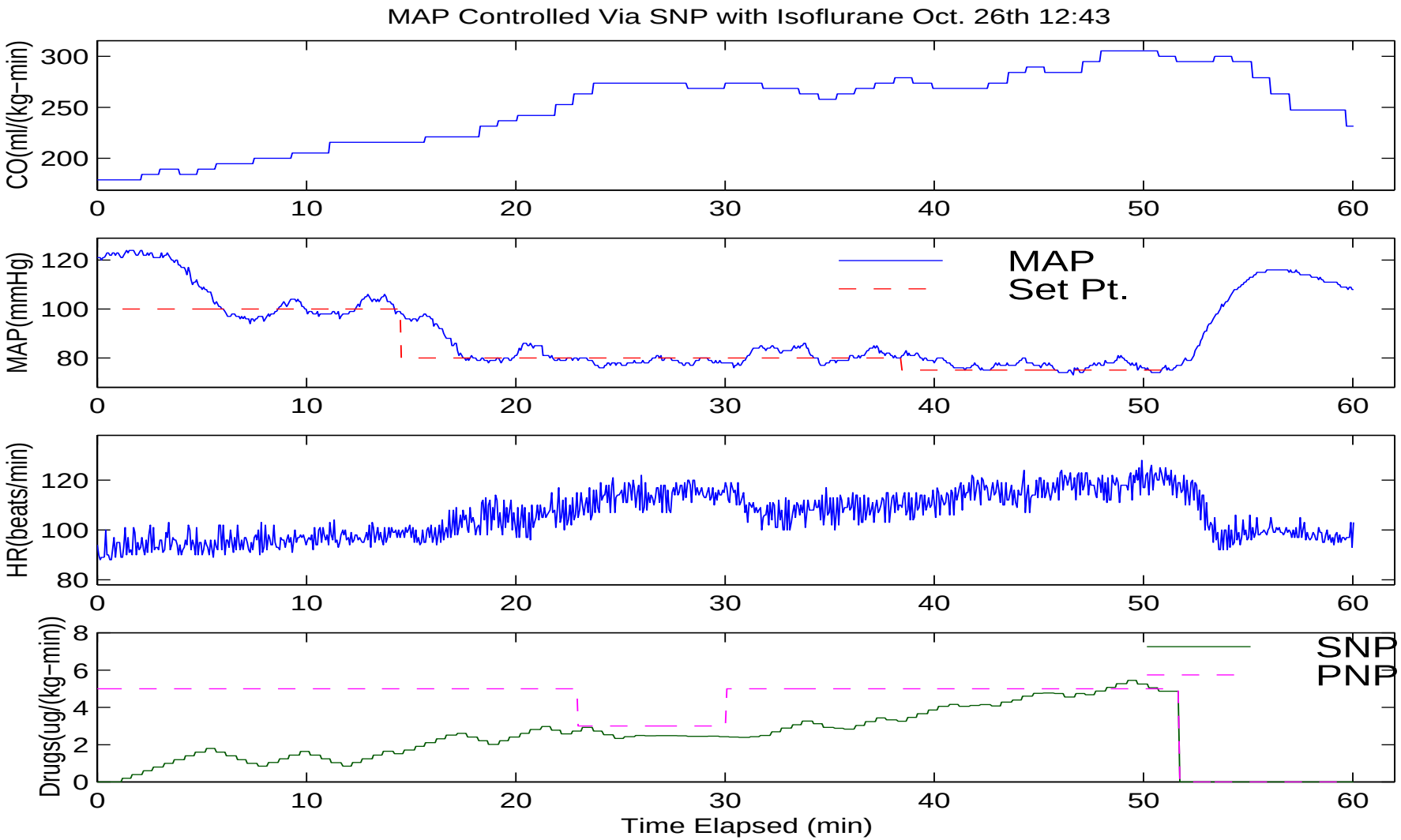
MMPC Issues

- Tuning of MPC
- Choice of model banks
  - first order + time delay
  - number of banks to cover a given range of gains, time constants and time delays
- Structure of the weighted bank
  - model structure/order evolves
  - over-specification ?
- Bayesian weighting
  - designed to converge to one model
  - blending of models is preferred - detune convergence

1. MAP Regulation (SISO)



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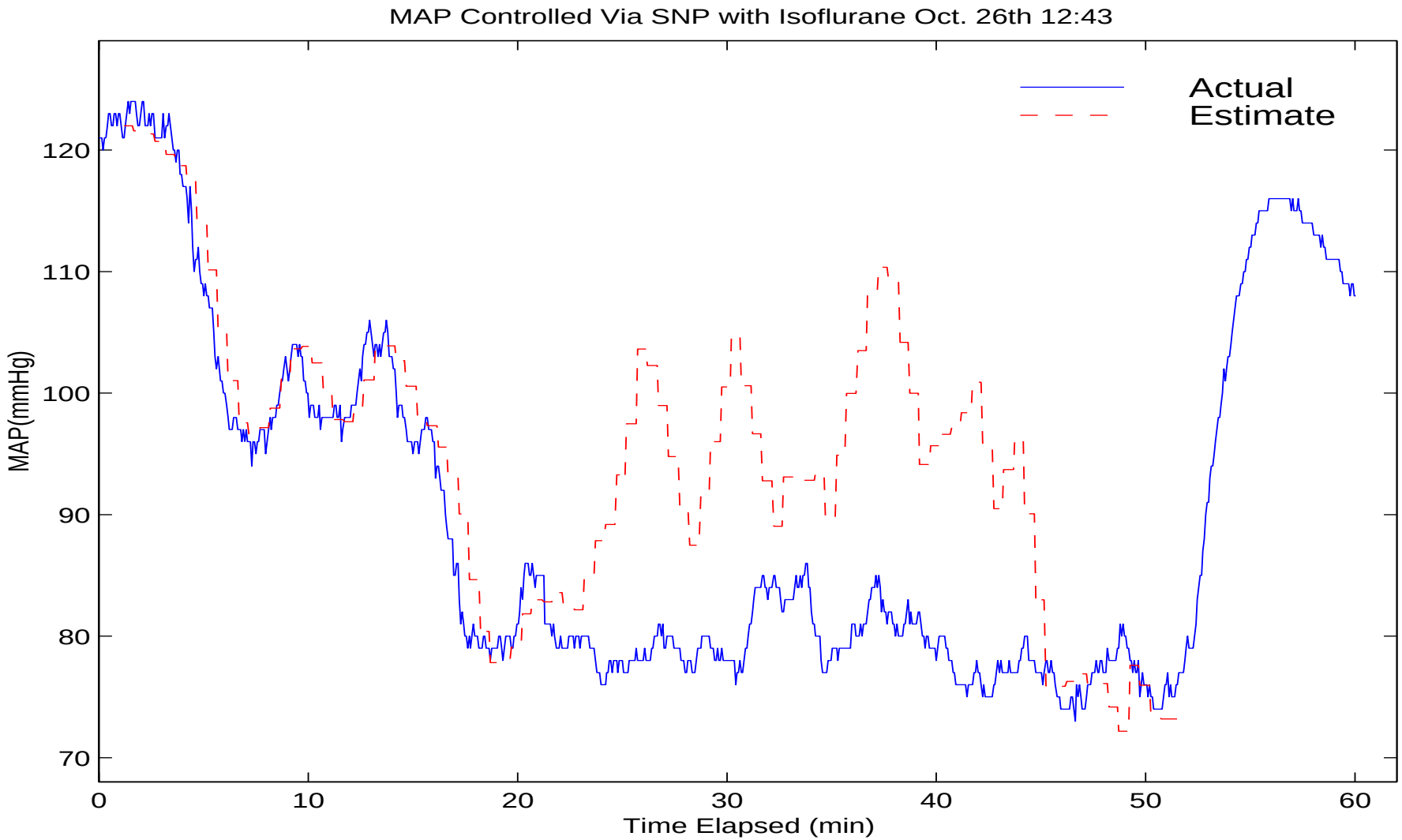
1. Weighted-Model Tracking



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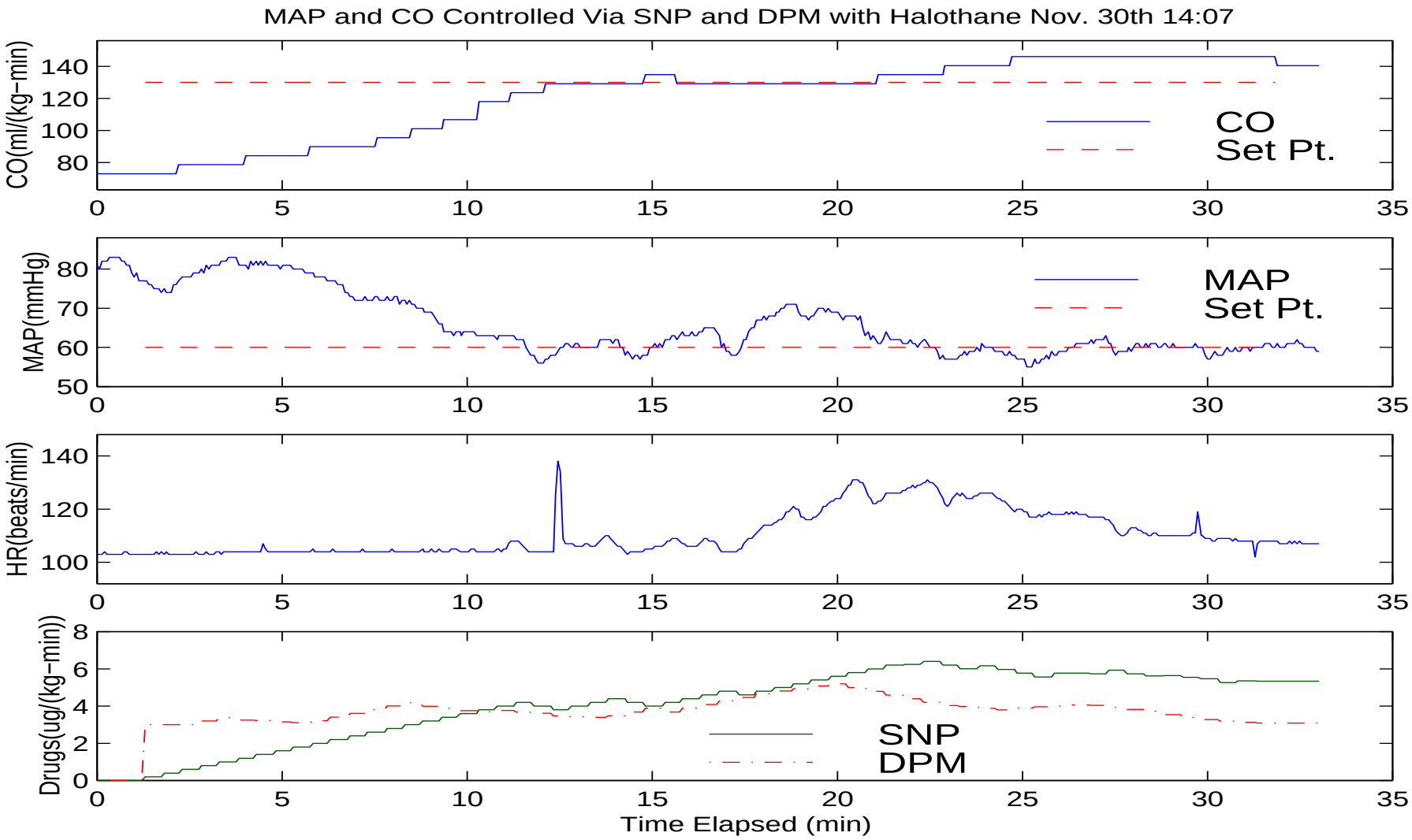
2. MAP and CO Regulation (MIMO)



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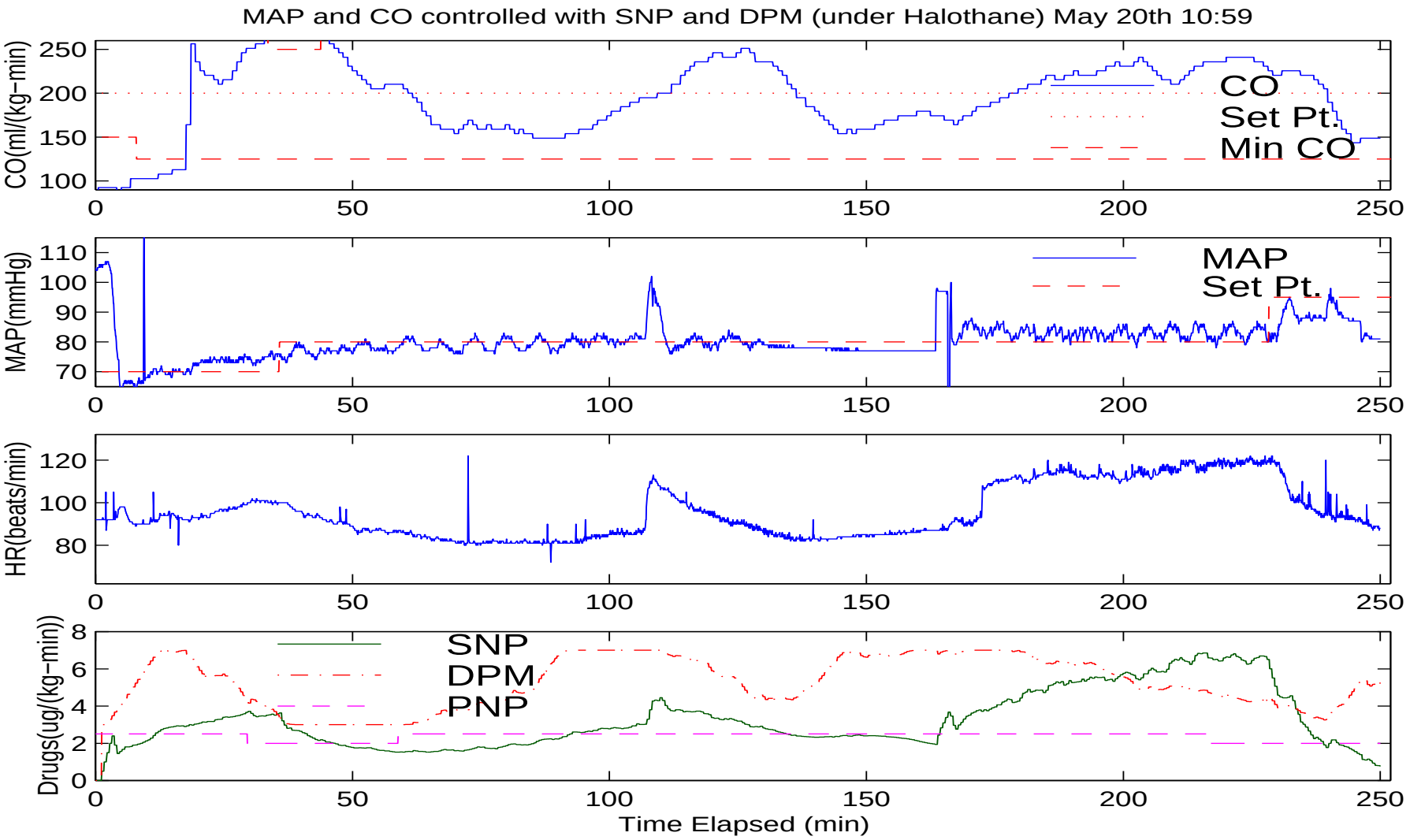
3. MAP and CO Regulation (MIMO)



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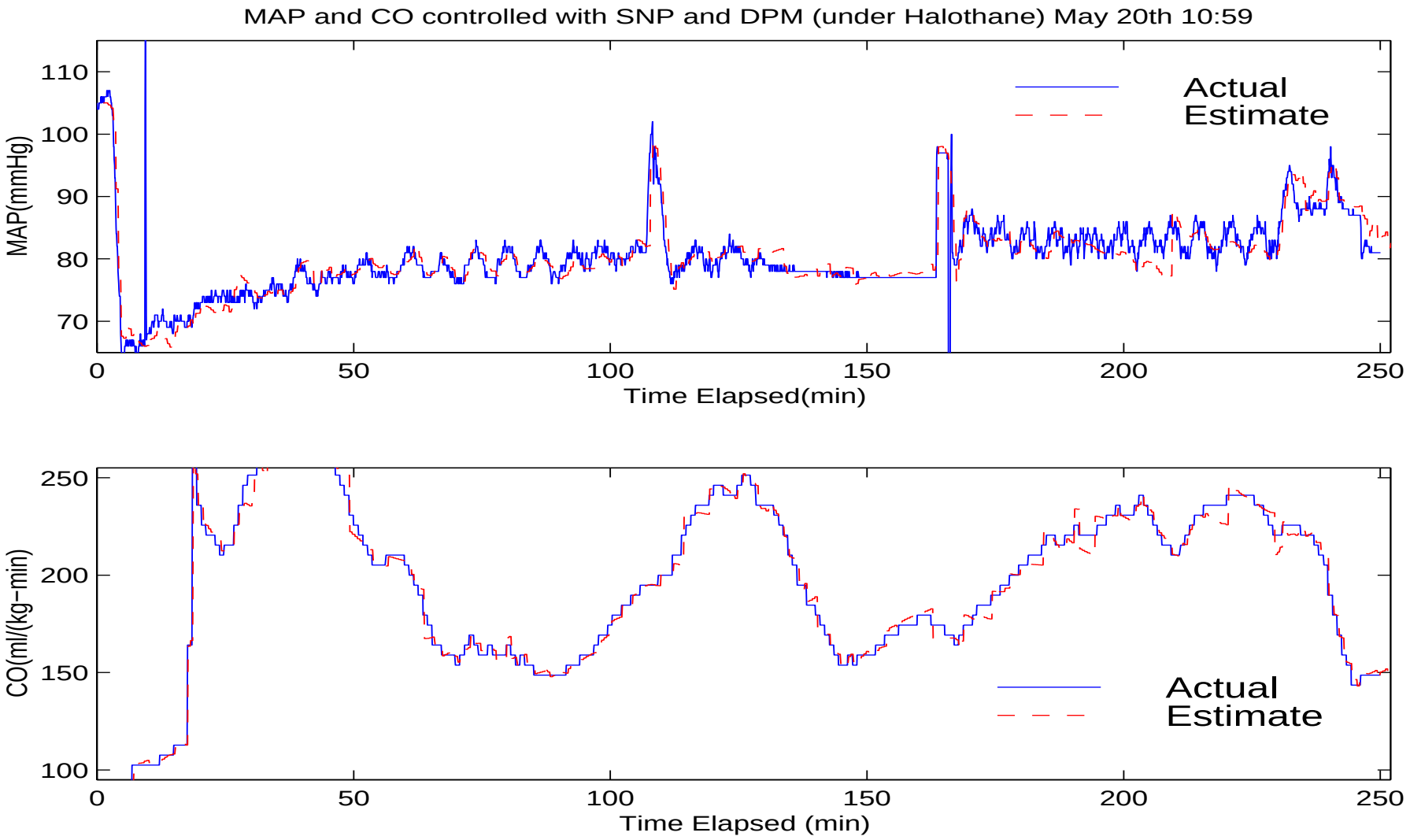
3. Weighted-Model Tracking



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Summary

- Multiple model predictive control approach
  - handling constraints
  - weighted model bank provides a flexible and bounded prediction model to handle inter- and intra patient variability
  - need for weighting schemes that are more conducive to blending
- Future work
  - experiments with induce congestive heart failure
  - develop weighting scheme more conducive to blending
  - develop MIMO model bank

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