

INDICIAL PREDICTION SYSTEM - QUICK TOUR -

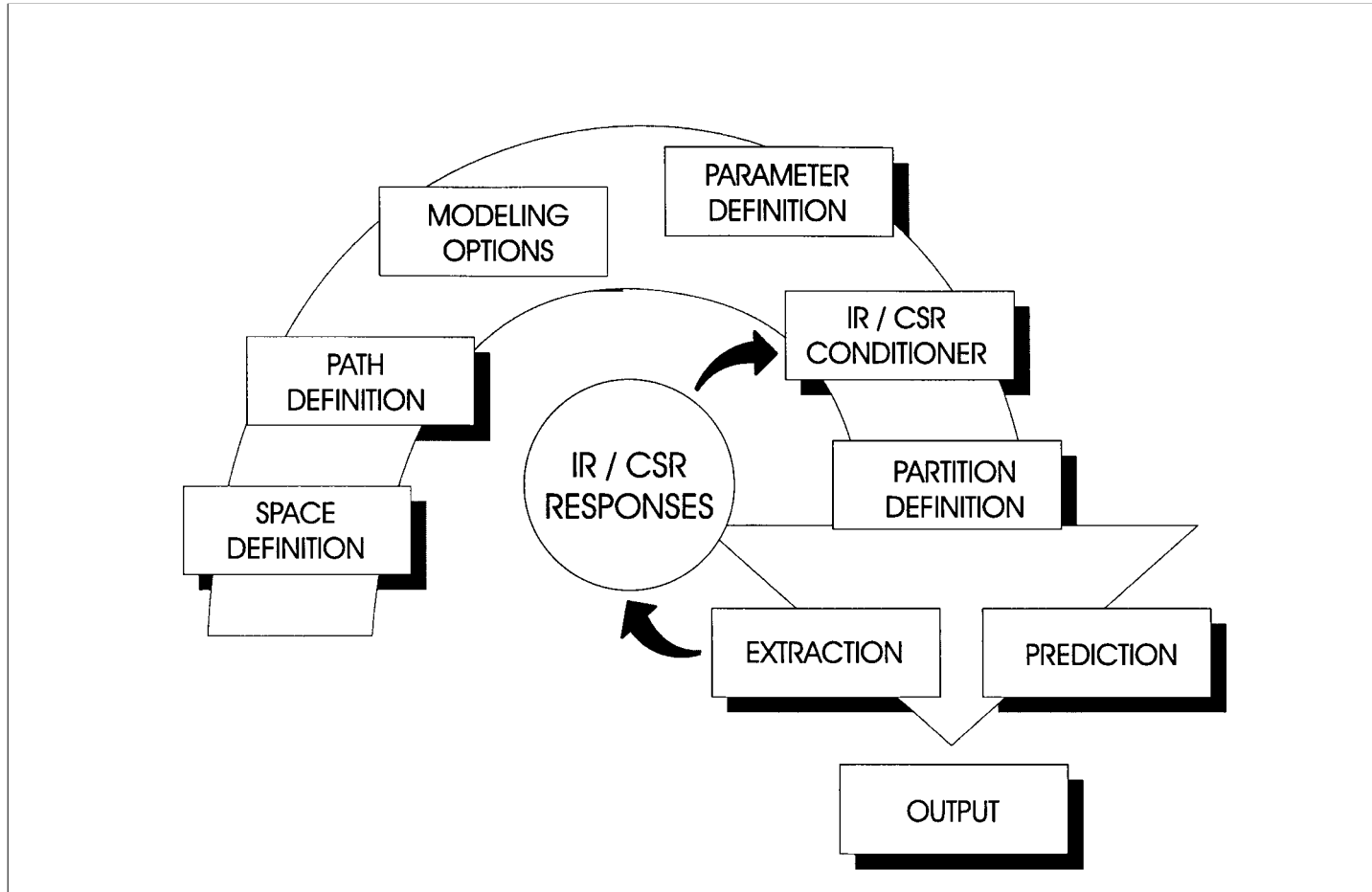
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October 1998

Nielsen Engineering & Research, Inc.
Mountain View, CA



IPS Overview



The IE and IP Programs Share Common Module Components.

Hardware / Software Requirements

- **The code compiles on the following systems**

HARDWARE	Operating System	F90 Compiler	C Compiler	Current Version
SUN	Solaris 2.x	Craysoft	gcc	✓
SUN	Solaris 2.x	SunPro	SunPro	✓
SGI	Irix 6.2	MIPSpro	Mipspro	✓
HP	HPUX 10.2	HP	HP	-
INTEL	Linux	NagWare	gcc	✓

- **Additional software required to compile**
 - gmake: GNU version of make[†]
 - perl: practical extraction and report language, version 5
 - gcc: GNU version of C-compiler (needed if system does not already have a C-compiler)[†]
 - pgplot: free device-independent plotting library

[†] Software is freeware, protected under GPL

Indicial Theory

If
$$\delta\mu(t) = \mu_{\epsilon}(t, \tau) \frac{d\epsilon(\tau)}{d\tau} \delta\tau + O(\delta\tau)^2$$

and
$$\mu_{\epsilon}(t, \tau) = \mu_{\epsilon}(t - \tau, 0) \equiv \mu_{\epsilon}(t - \tau)$$

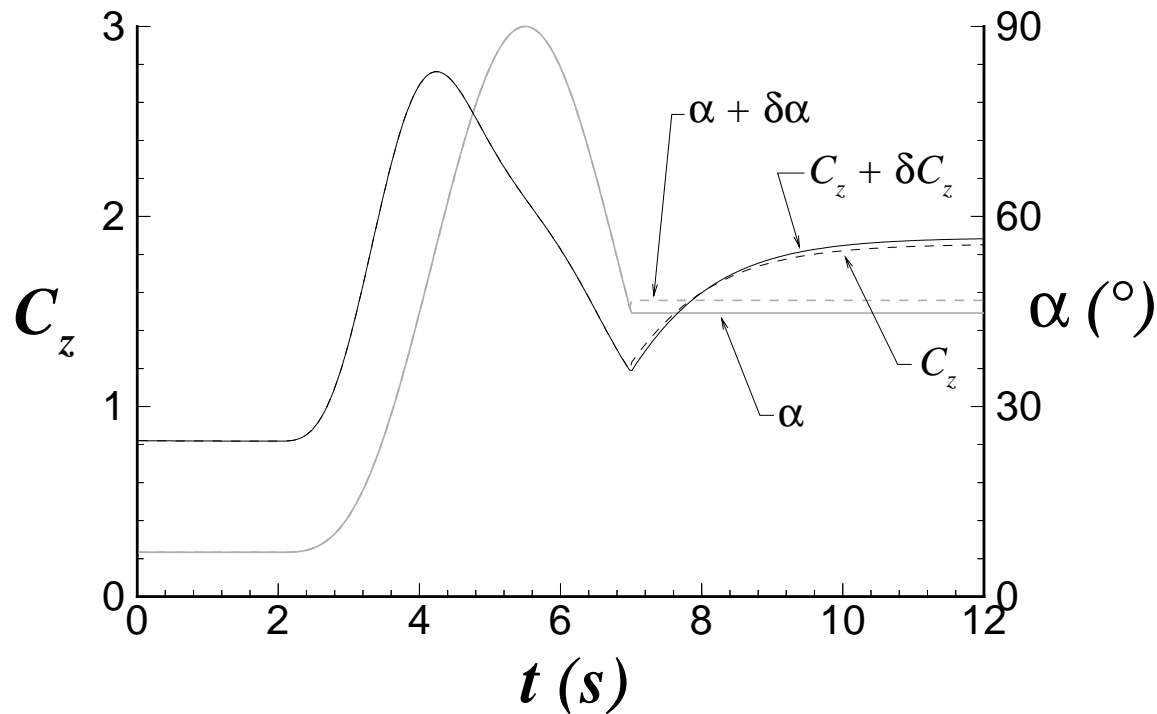
Then:
$$\mu(t) = \mu_{\epsilon}(t)\epsilon(0) + \int_0^t \mu_{\epsilon}(t - \tau) \frac{d\epsilon(\tau)}{d\tau} \delta\tau$$

Nonlinear Indicial Theory



$$\begin{aligned}\Delta \mu(t) &= \int_0^{\tau_c^-} \mu_\epsilon(\epsilon(\xi); t, \tau) \frac{d\epsilon}{d\tau} d\tau \\ &+ \Delta \mu^{CS}(\epsilon(\xi); t, \tau_c) \\ &+ \int_{\tau_c^+}^t \mu_\epsilon(\epsilon(\xi); t, \tau) \frac{d\epsilon}{d\tau} d\tau\end{aligned}$$

Indicial Response



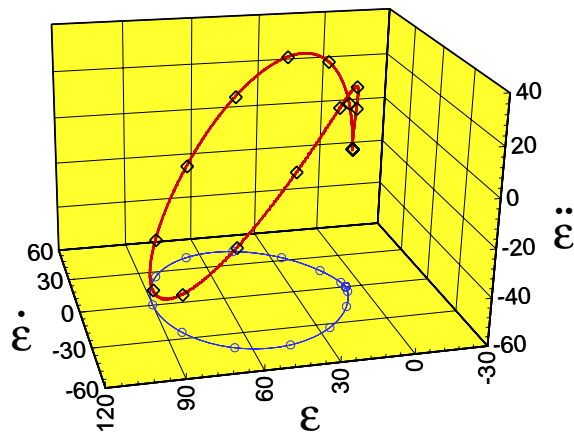
$$IR = \lim_{\delta \alpha \rightarrow 0} \frac{\delta C_z}{\delta \alpha}$$

Nonlinear Indicial Model

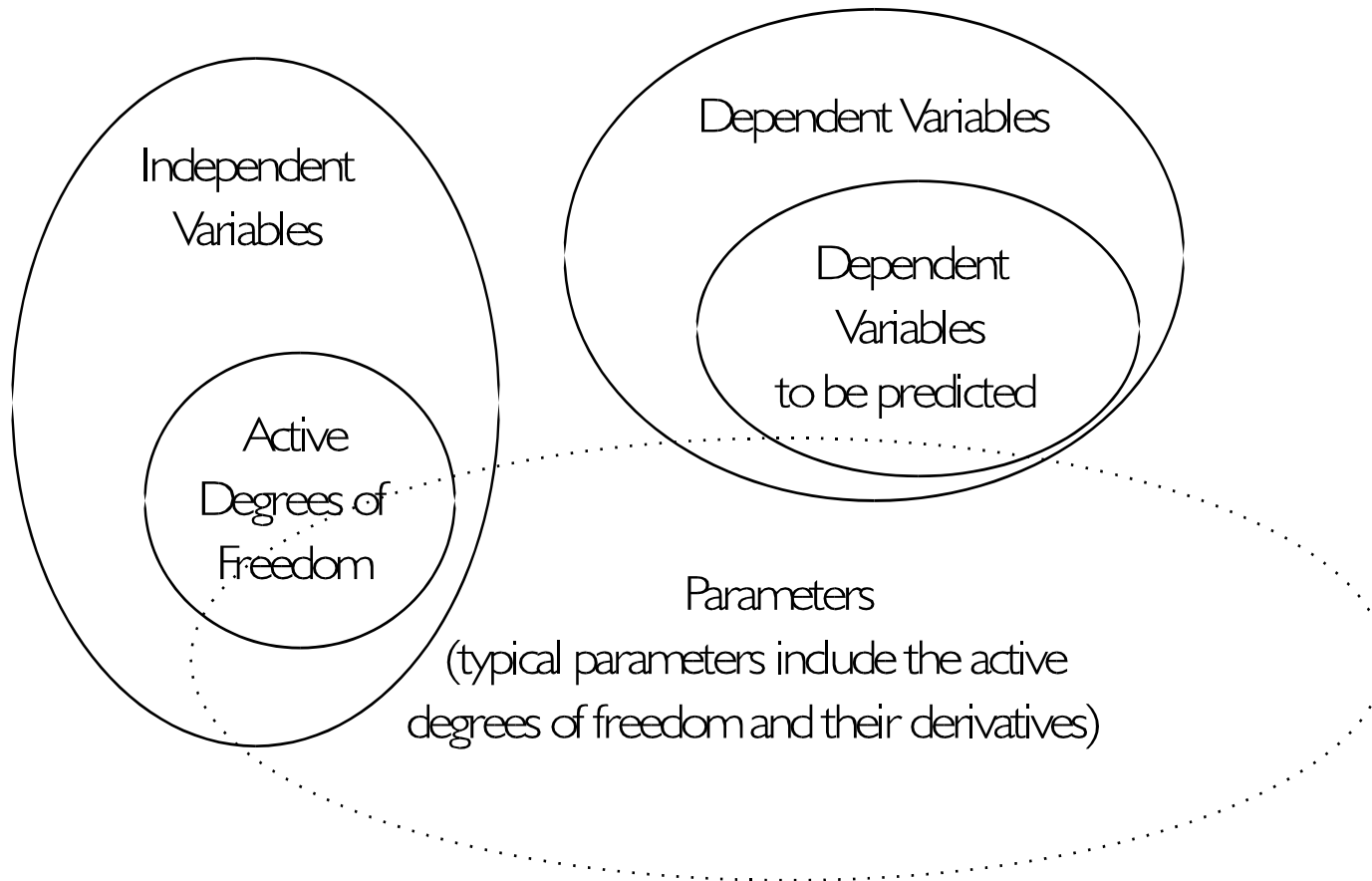


$$\Delta \mu(t) = \int_0^t \mu_{\epsilon}(\epsilon(\xi); t, \tau) \frac{d\epsilon}{d\tau} d\tau$$

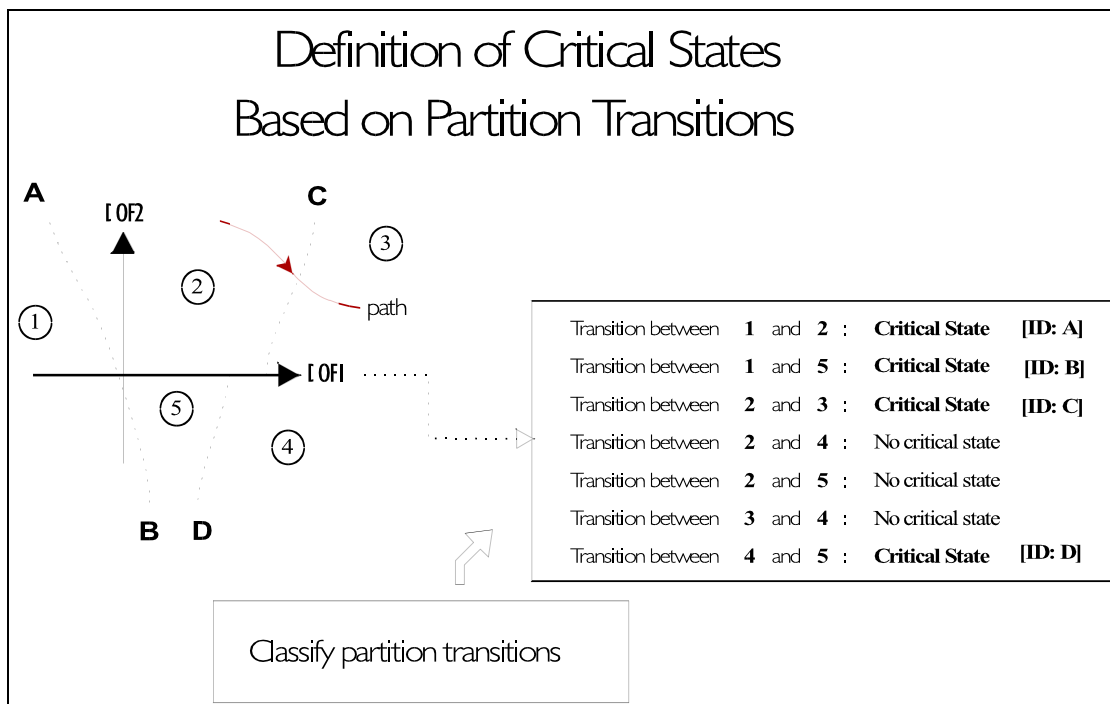
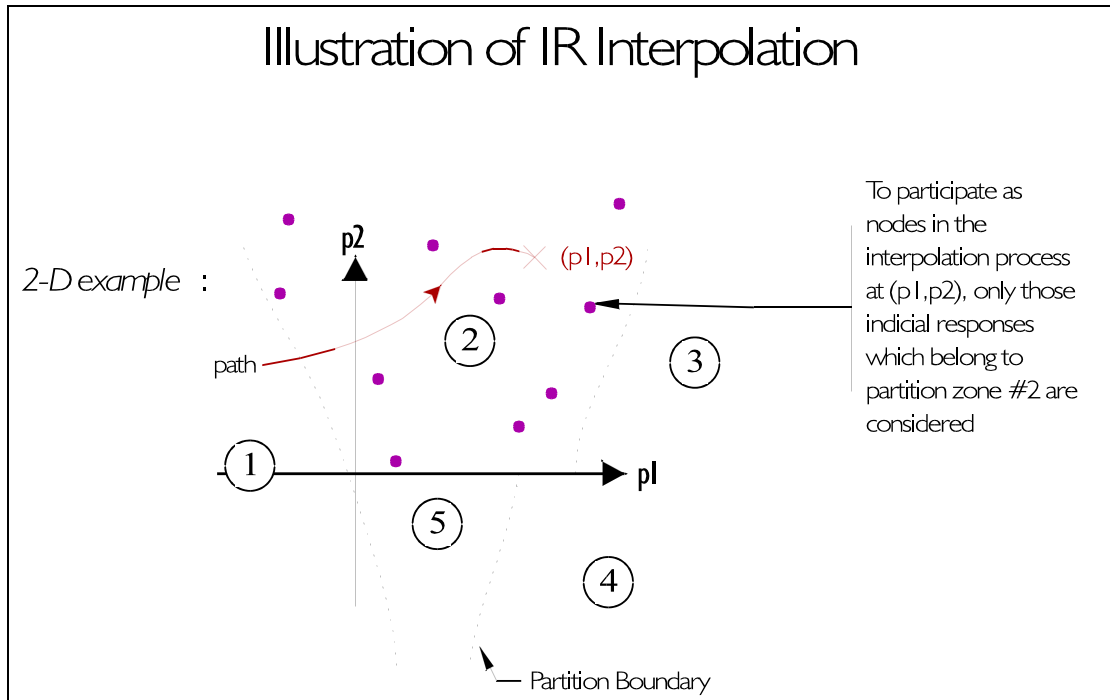
$$\approx \int_0^t \mu_{\epsilon}(t-\tau) \Big|_{\epsilon(\tau), \dot{\epsilon}(\tau), \dots} \frac{d\epsilon}{d\tau} d\tau$$



Terminology



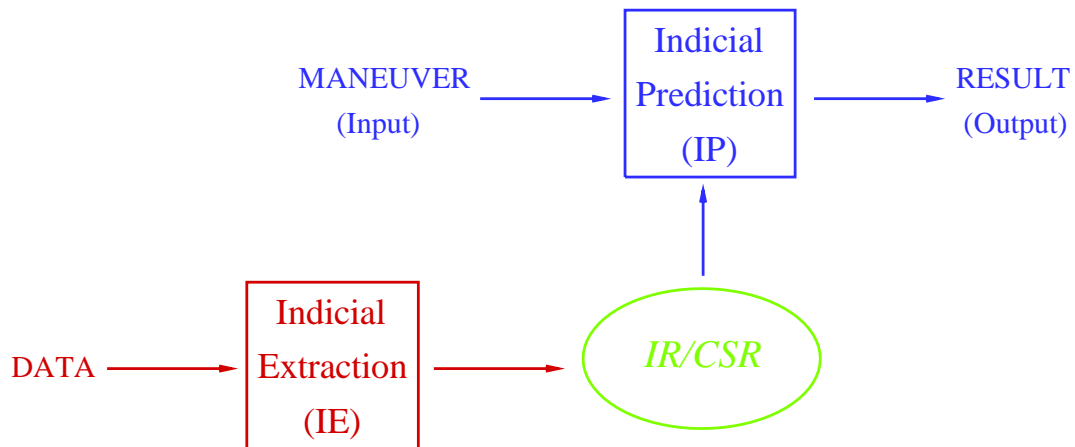
IR/CSR Space Partition



Direct/Inverse Problems



$$\int_{\Omega} input \times system d\Omega = output$$

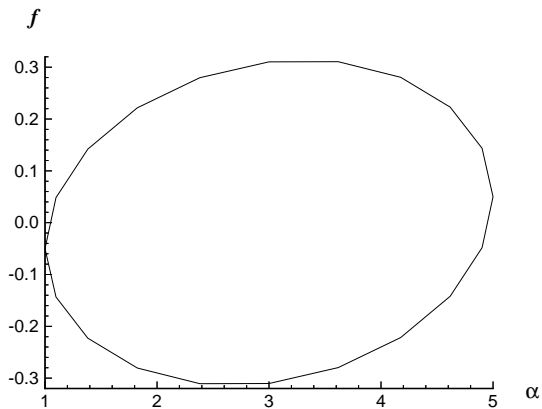


Algorithm

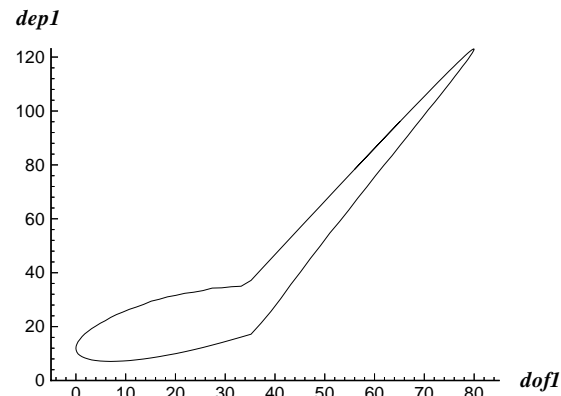
- $$IR(t) = IR_{QS} + DR(t)$$
$$DEP \leftarrow \int_0^t IR_{QS} \dot{DOF} d\tau + \int_0^t DR(t-\tau) \dot{DOF}(\tau) d\tau$$
$$DEP \leftarrow DEP + \sum_{CS} CSR_{QS} + \sum_{CS} CSR_{DR}(t-t_c)$$

- **Multiple DOF capability**
- **Arbitrary dimensional parameterization** (discrete or continuous)
- **Computational engines:**
 - Quadrature operations
 - Interpolation operations

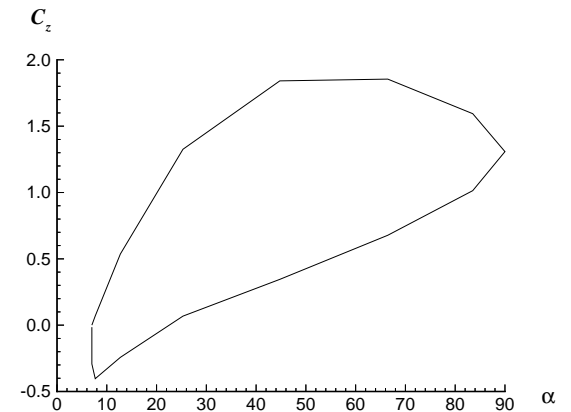
Sample Outputs



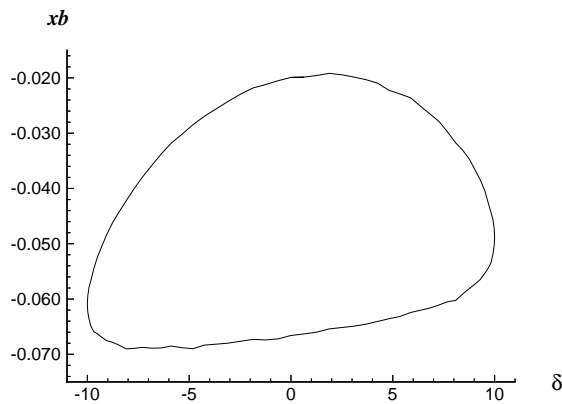
Case 'linear'



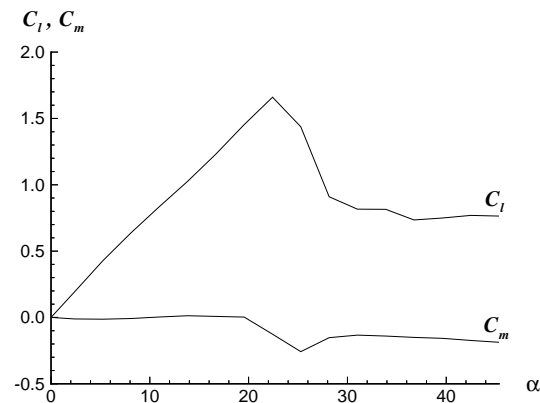
Case 'nlir'



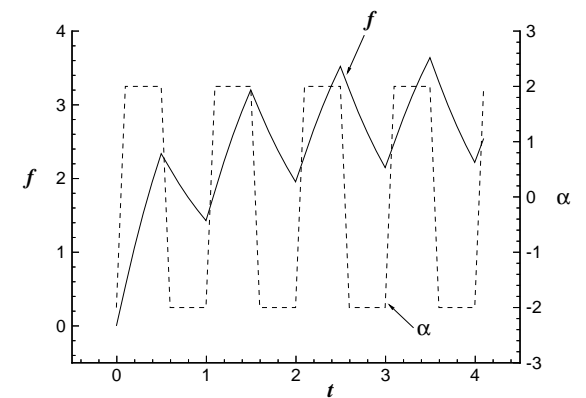
Case 'GK'



Case 'gursul'

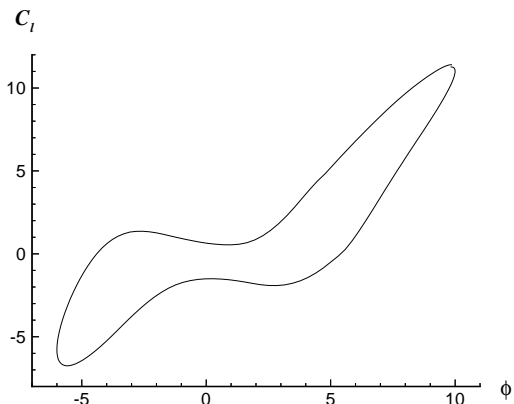


Case 'NN'

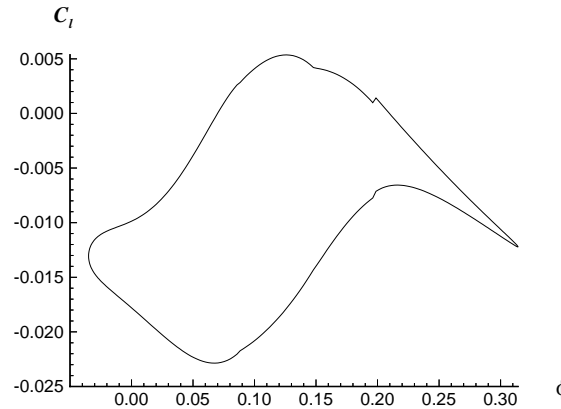


Case 'xlin2'

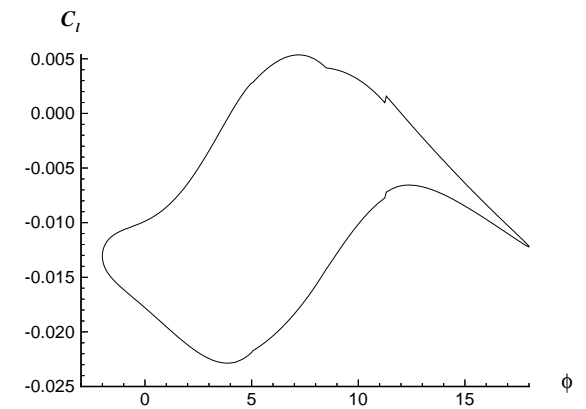
Sample Outputs (Cont'd)



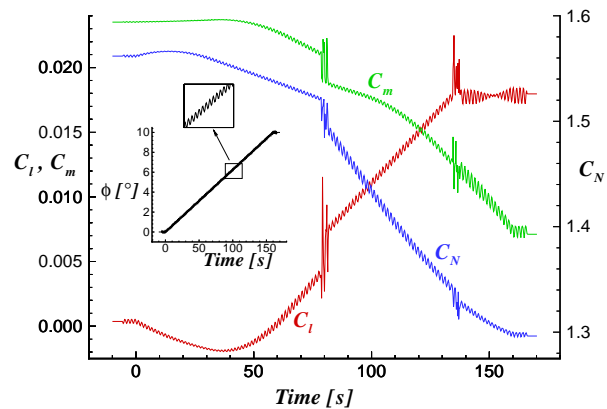
Case 'reno97'



Case 'myatt'



Case 'myattdeg'



Case 'delta_all'

Extraction: Theory



$$DEP^{dyn}(t_j) = \int_0^{t_j} DR(t_j - \tau) \dot{DOF}(\tau) d\tau$$

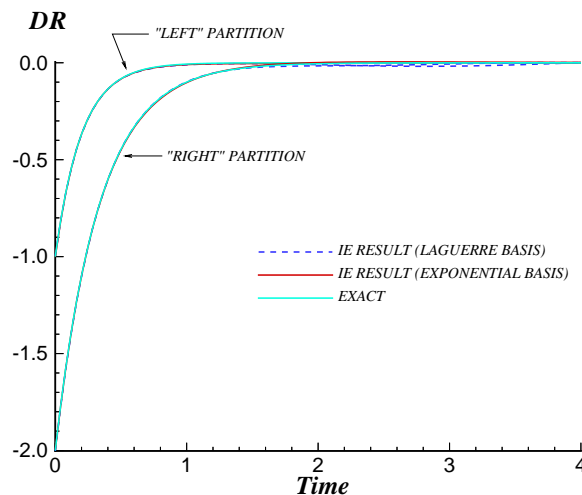
- **Linear interpolation:** $DR(t-\tau) = \sum_k w_k(\tau) DR_k(t-\tau)$
- **Basis function expansion:** $DR_k(t) = \sum_i x_{i,k} f_{i,k}(t)$

$$[A][x] = [b]$$

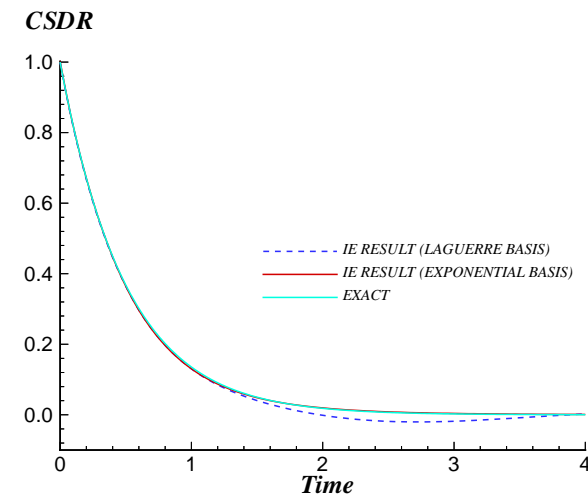
Solution by singular value decomposition

Extraction: Sample Results

- **Linear system, complete set of basis functions**
→ 4-digit accuracy
- **Linear system, incomplete basis functions**
20% time constant error → 5% accuracy on extraction
→ 1% accuracy on prediction
- **Nonlinear system, incomplete basis functions:**



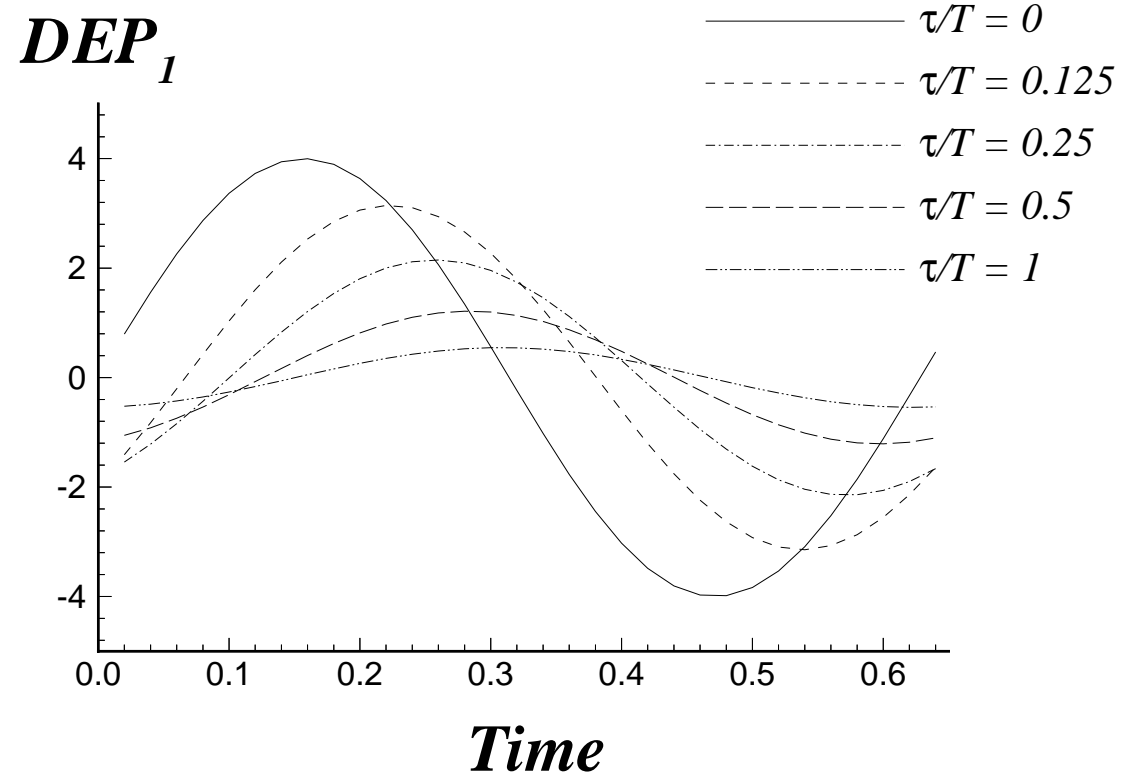
Extracted IR Nodes



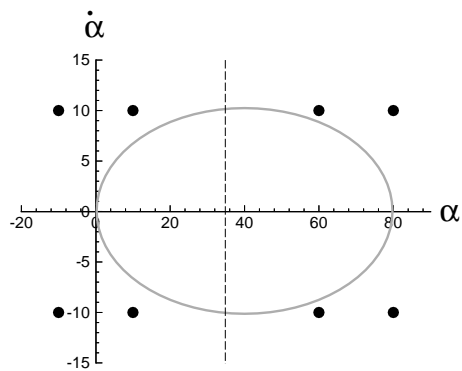
Extracted CSR Node

Linear Indicial Response

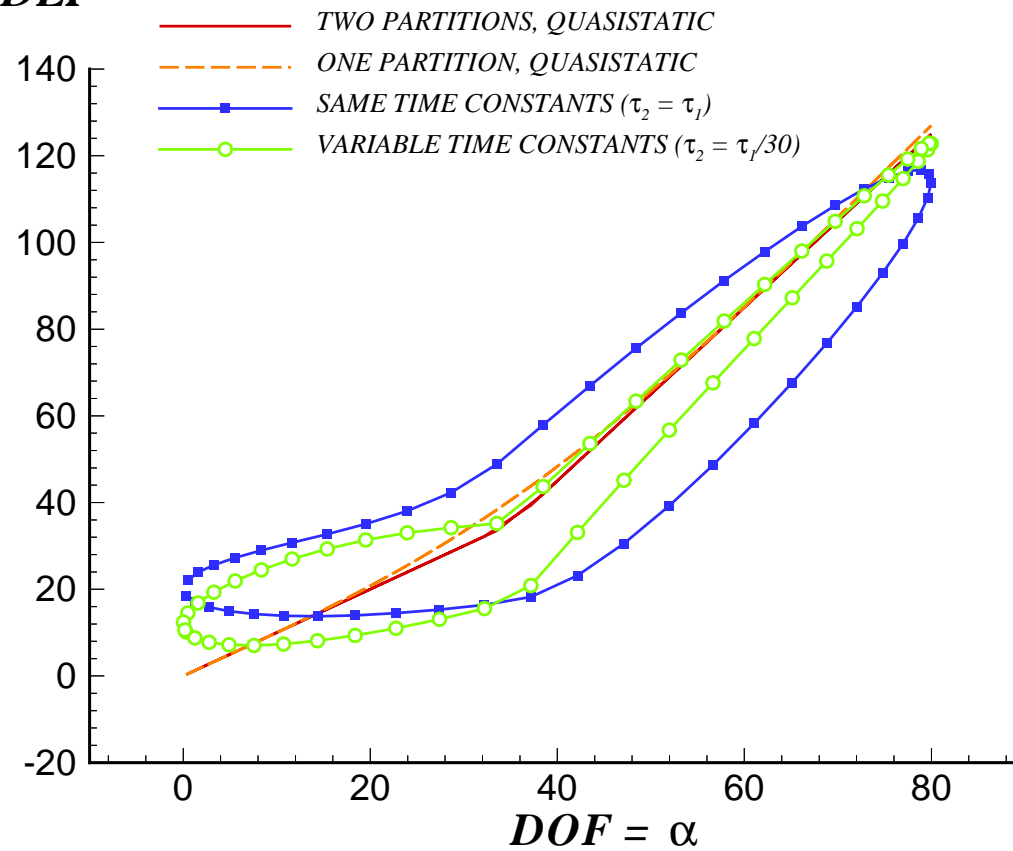
Ratio τ/T	Amplitude	Phase
0	4	0°
0.125	3.146	-38.1°
0.25	2.149	-57.5°
0.5	1.214	-72.3°
1	0.629	-81.0°



IR Space Partitioning

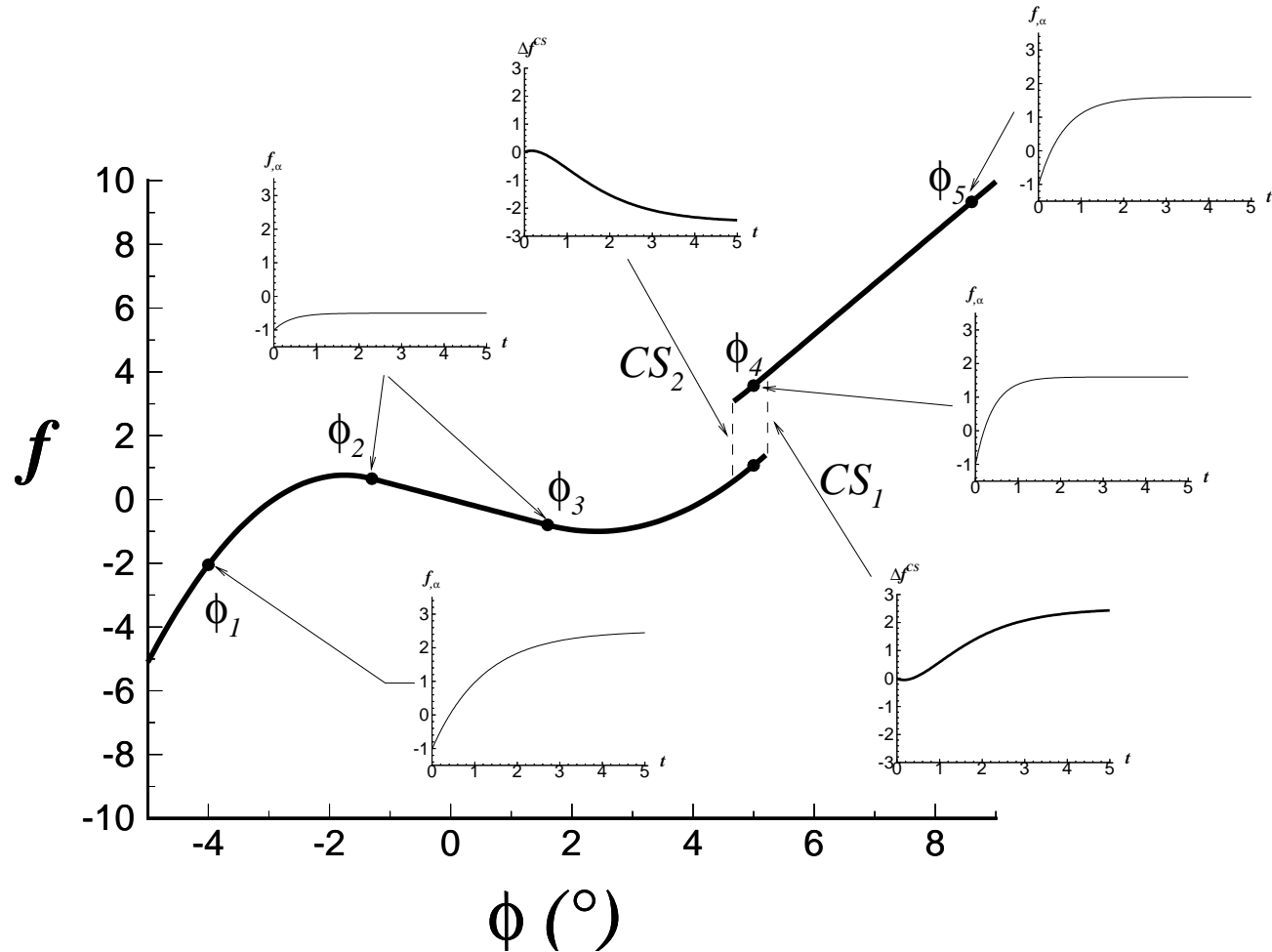


DEP



'reno97' synthetic data example

- Static hysteresis case, with 5 IRs and 2 CSRs



Critical State Hysteresis

