Introducing OpenMx

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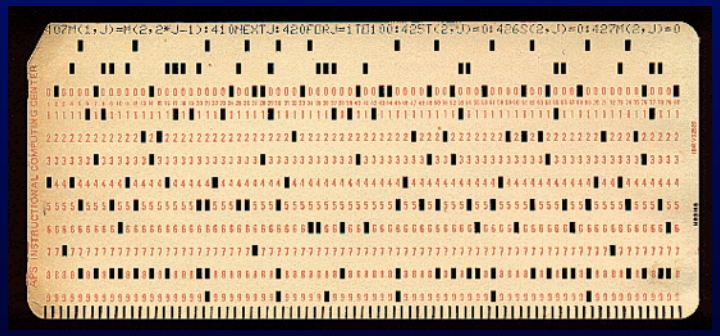
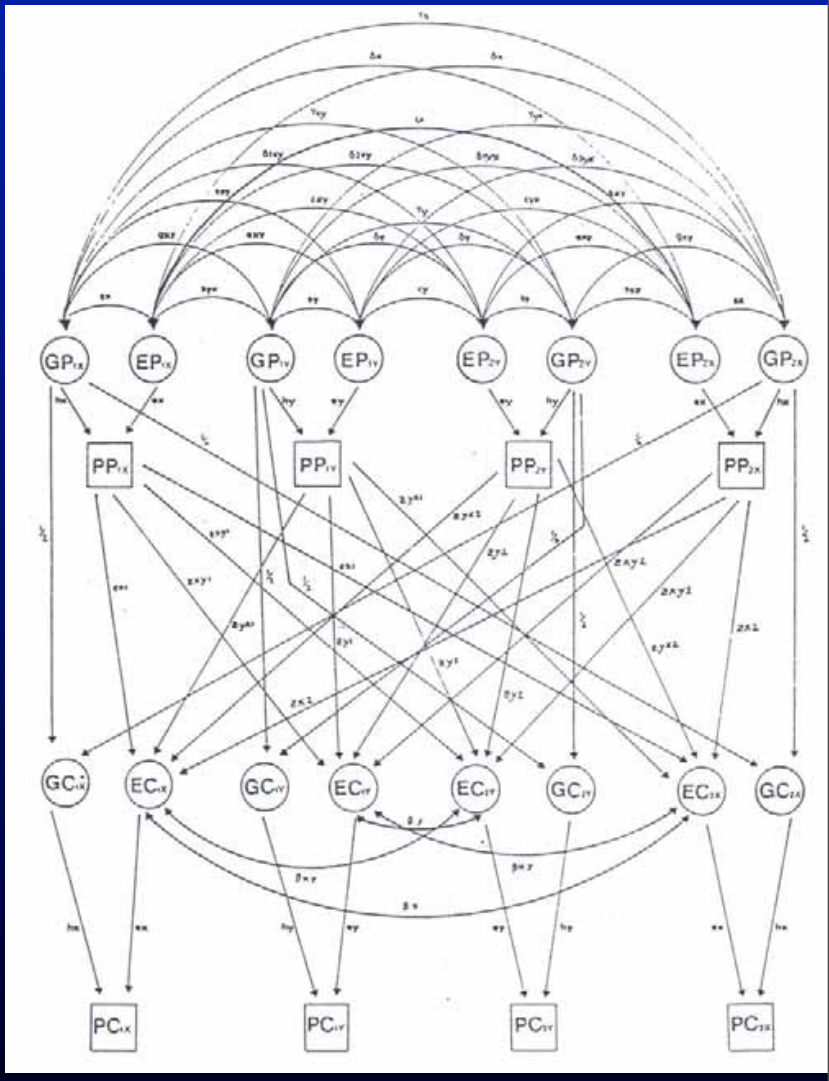
Overview

- History of Mx and OpenMx
- Description of OpenMx Structure
- Introduction to mxMatrix and mxAlgebra commands

MCN background

Prehistoric Beginnings





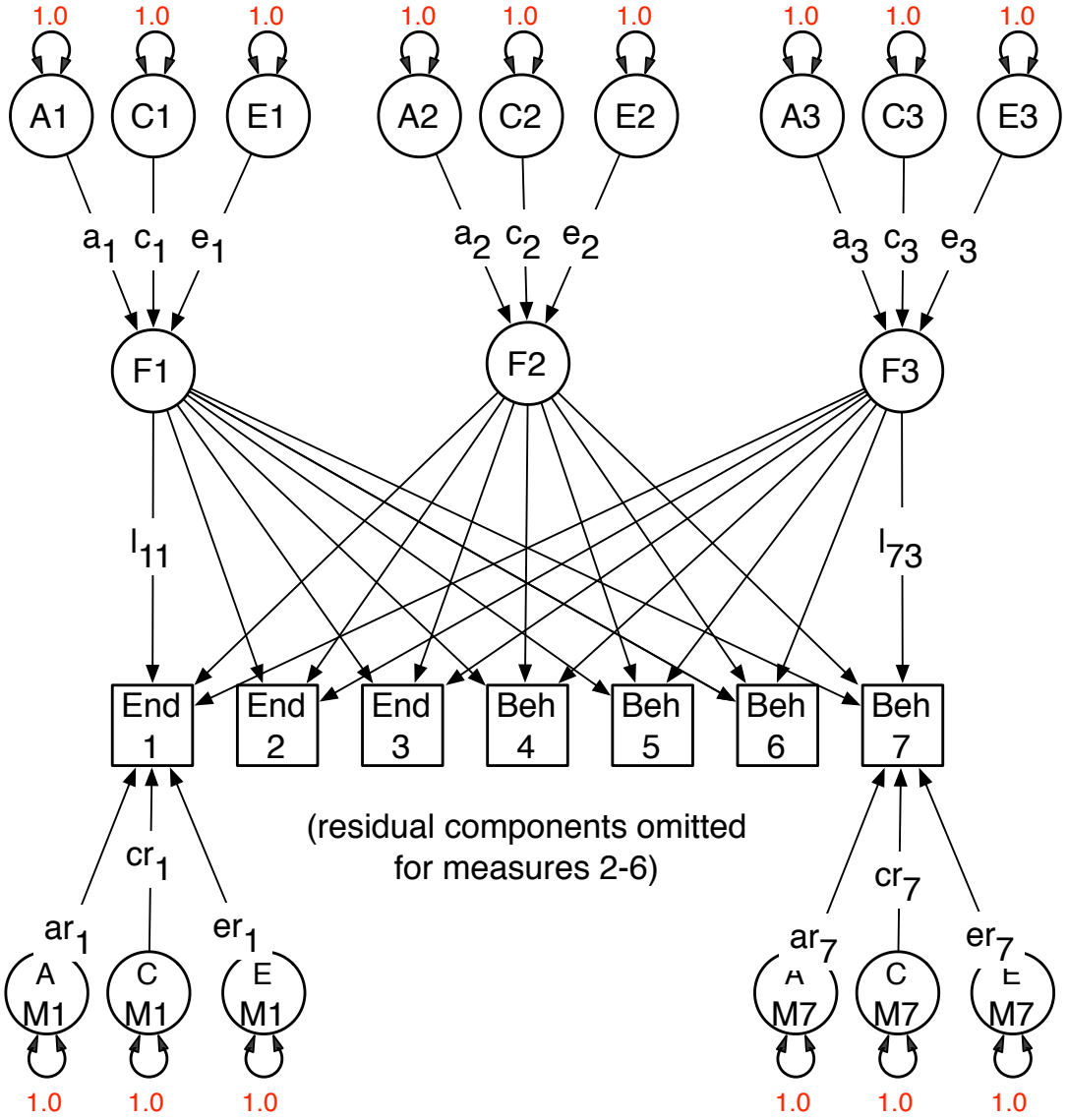
How did OpenMx get started?

- Twin Methodology Workshops 1987-1989
- Use of LISREL
- Limitations of LISREL, EQS et al
- Experience with Optimization & Matrix Algebra & Calculators in FORTRAN
- January 1990: start connecting matrix algebra interpreter with numerical optimizer

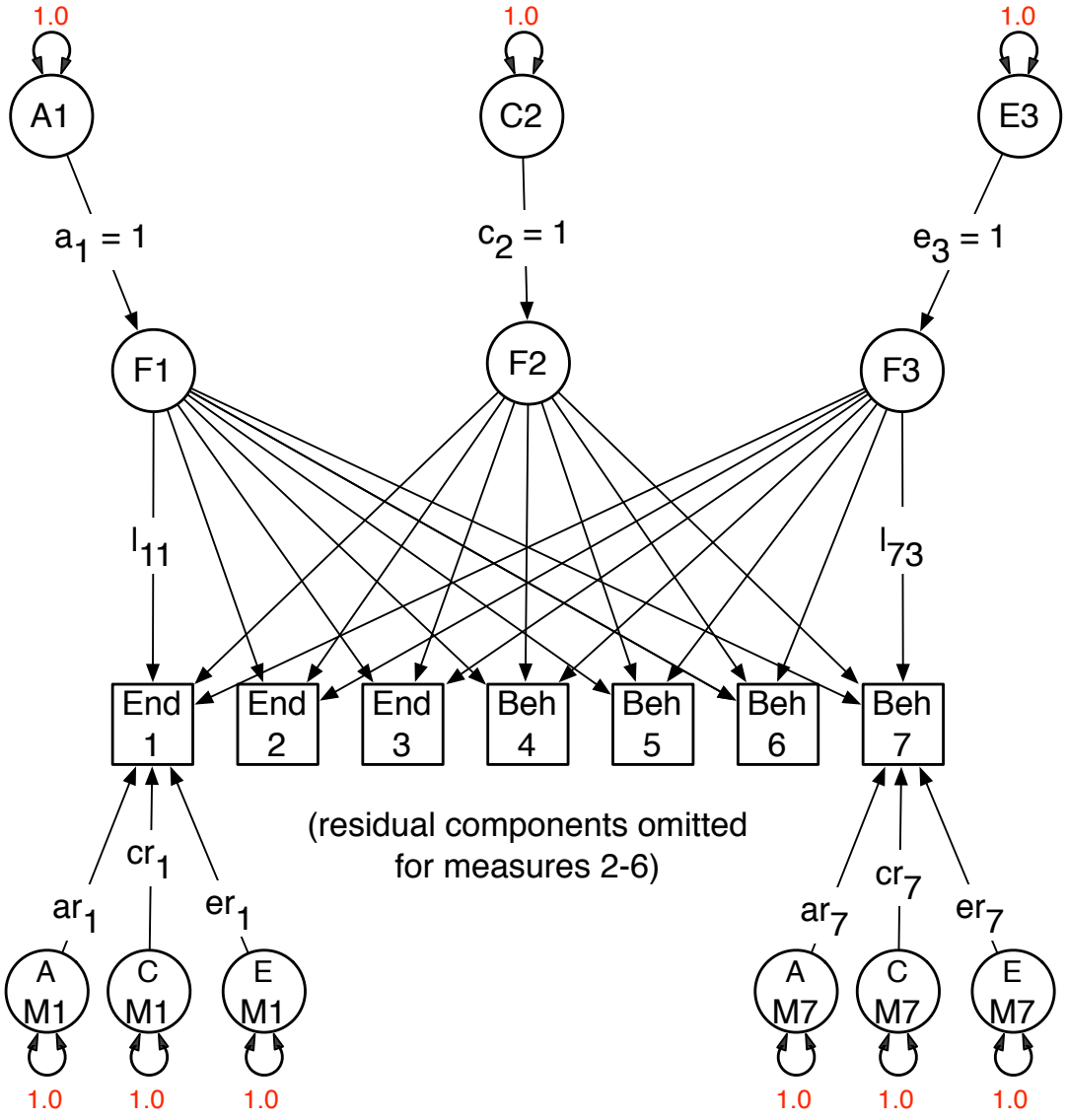
Motivation for Mx & OpenMx

- Wide variety of models
  - Univariate Twin ACE ADE
    - Continuous Data
    - Binary/Ordinal Data
  - Multivariate
    - Saturated (e.g., Cholesky)
    - Biometric Factor
    - Psychometric Factor
    - Direction of Causation
    - Comorbidity Models, Endophenotypes
  - Extended Pedigrees, Adoption, Twin-Family

Psychometric Factor Model

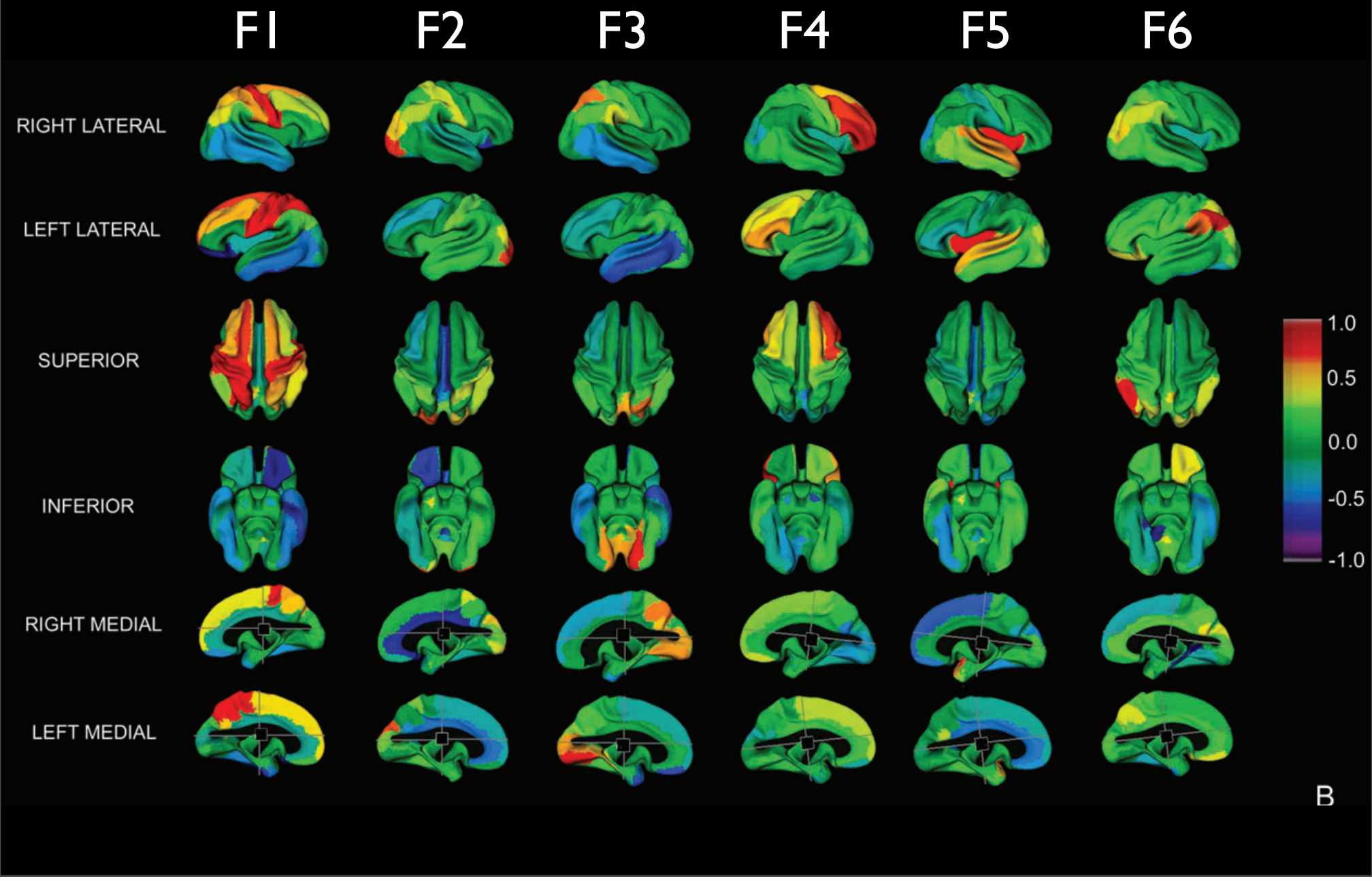


Biometric Factor Model



Independent pathway model is submodel of 3 factor common pathway model

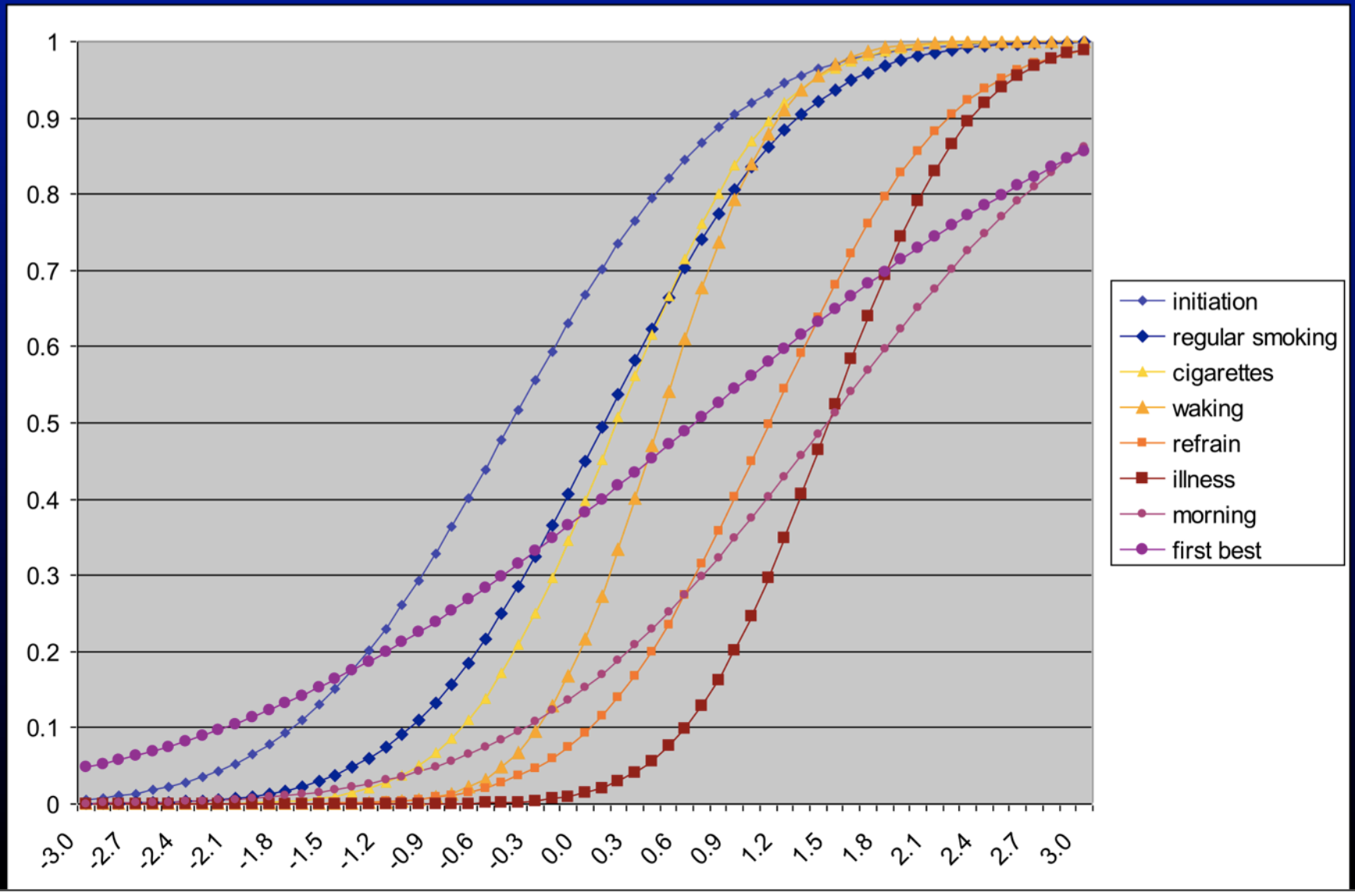
Genetic Factor Loadings



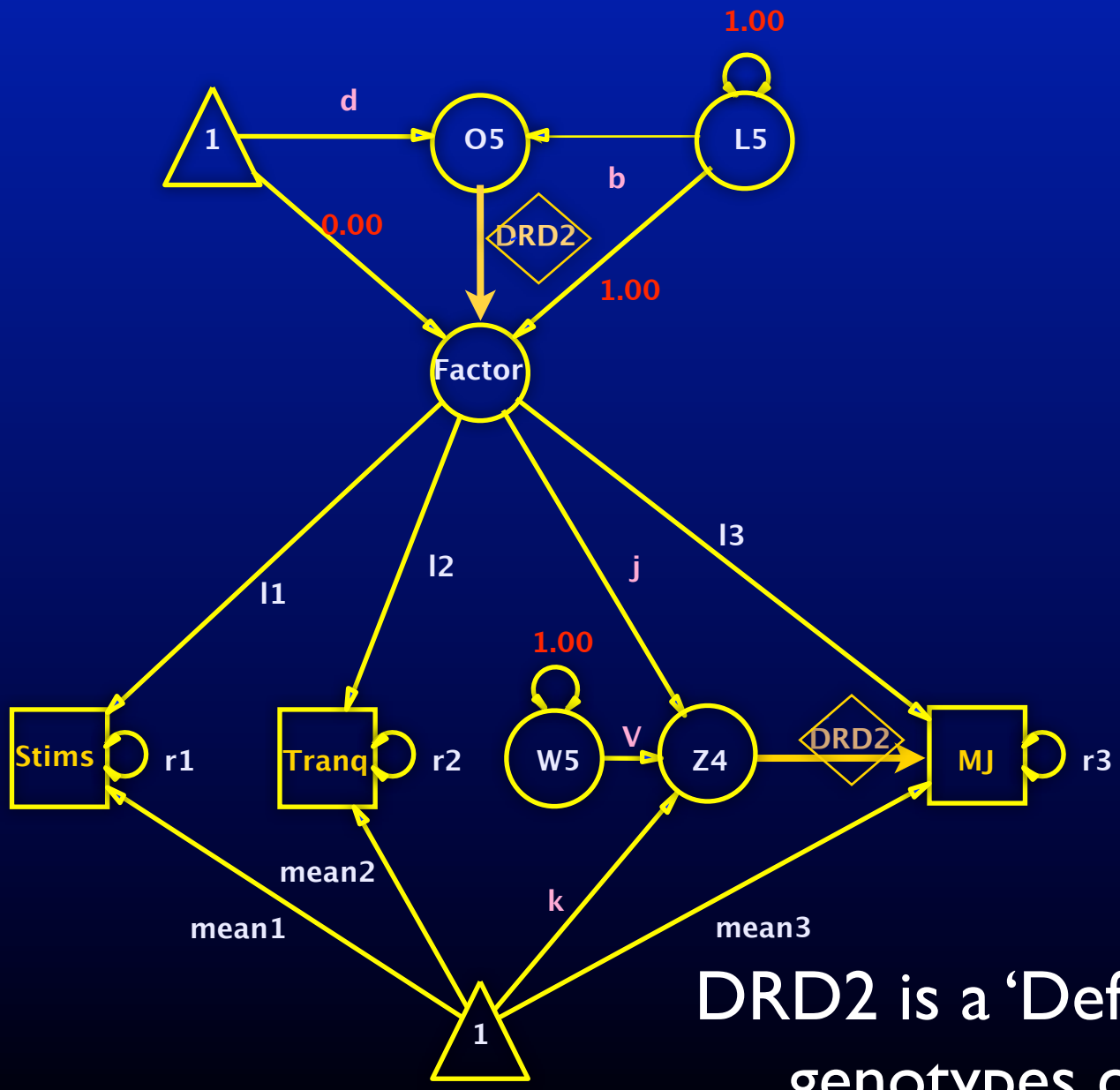
Motivation for OpenMx II

- Interactions
  - Heterogeneity, Meta-Analysis
  - Sex-limitation, C/G×Sex
  - Measurement Invariance & IRT
  - Continuous & discrete moderators
- Mixture Distributions
  - Twins: Uncertain Zygosity (Neale 2003)
  - Linkage: Uncertain IBD
  - Association: Uncertain Haplotypes/Genotypes
  - Latent Class & Factor Mixture Models

Estimated Nicotine Dependence Item Characteristic Curves for 20-Year-Old Females



DRD2 in the Factor Model



DRD2 is a 'Definition Variable'
genotypes coded -1 0 1

Motivation for Mx & OpenMx III

- Missing Data
  - Longitudinal Studies
  - Conditional Models (initiation & dependence)
- Dynamical Systems
  - Latent Growth Curves
  - Dampened Oscillators
- Multilevel Modeling
  - School/Batch Effects

More Information

- Published articles & book chapters
  - http://www.vipbg.vcu.edu/neale-articles.shtml
- OpenMx website
  - http://openmx.psyc.virginia.edu
- Dutch classic Mx website
  - http://www.psy.vu.nl/mxbib
- Original Mx website
  - http://www.vcu.edu/mx

What's wrong with Classic Mx?

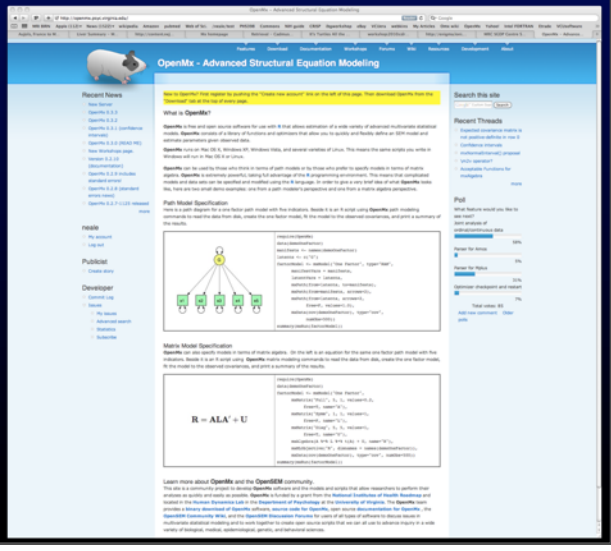
- Single programmer
  - Limited Tech Support
  - Limited Life
  - Limited Feature Enhancements
  - Limited Interoperability
- Spaghetti Code
- Idiosyncratic Positional-Dependent 'Specialist' Language
- Single Letter Matrices

What is OpenMx?

- Free, Open-source, full–featured SEM (XSEM) package
- Software which runs on Windows, Mac OS-X, and Linux
- A package in the R statistical programing environment

What Does OpenMx Offer?

- New approaches to model specification
- Path-style and matrix-style scripting
- Web–based forums, tutorials, and a wiki
- http://openmx.psyc.virginia.edu



Why Open Source?

- Community–based approach to software development
  - More people can work on its development
  - Code can be inspected and edited by anyone
- Scientific model
  - Acknowledge work of others
  - Contribute effort for the benefit of all
- Apache 2.0 license

Language Fundamentals

- R is a functional language
  - Easy to define new functions
  - Not strictly functional - some interactions
  - Everything is an Object
- OpenMx uses functions to build objects
  - mxModel() is a function
  - Arguments have an order
  - Order can be changed by naming arguments

OpenMx Essential Functions

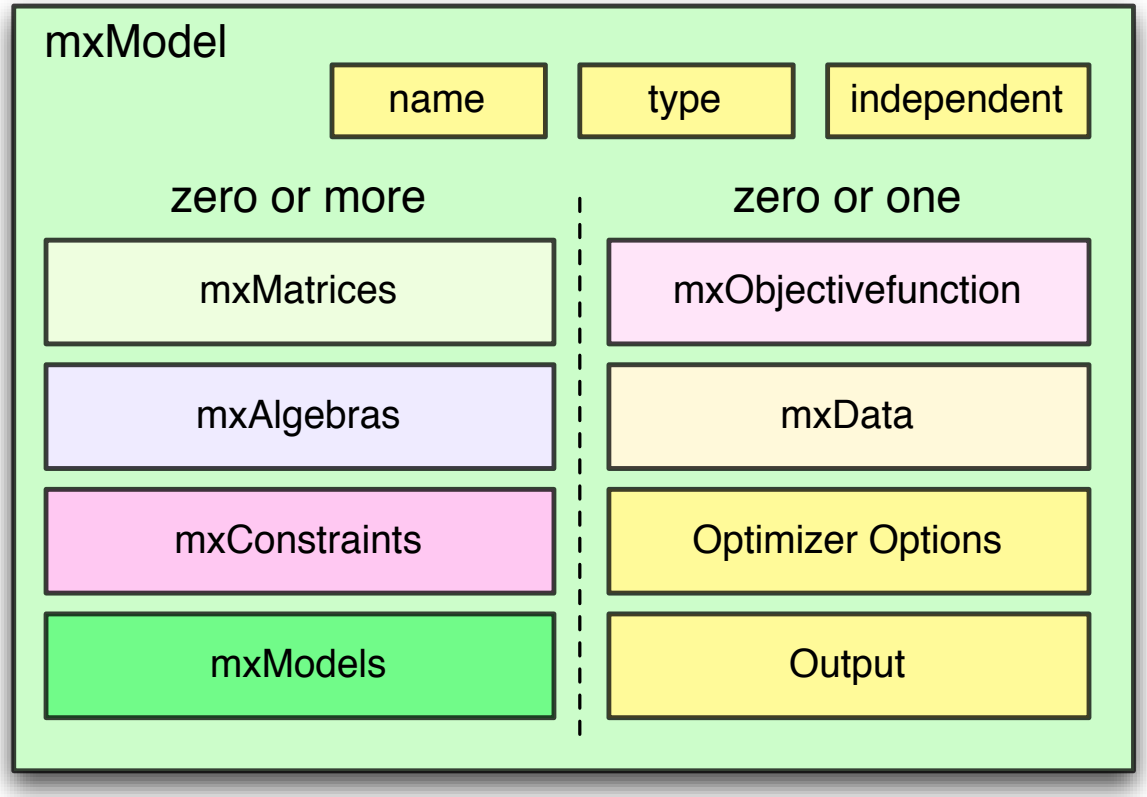
- mxModel()
- mxMatrix()
- mxAlgebra()
- mxData()
- mxFIMLObjective() *[+ mx*Objective()s]*
- mxRun()

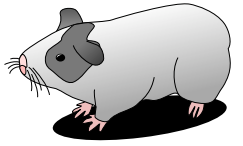
OpenMx Utility Functions

- mxOption()
- mxRename()
- mxEval()
- mxConstraint()
- mxPath()

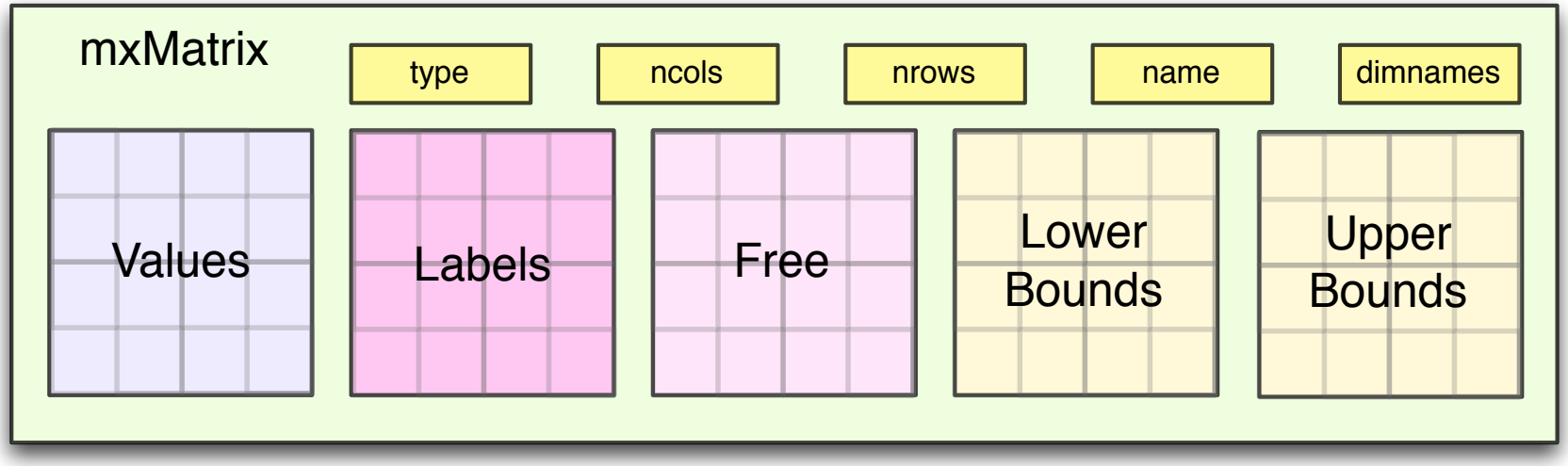
- Several others + any you make yourself
  - plus2 <- function (x) {x+2}

An MxModel Contains Objects and Other MxModels

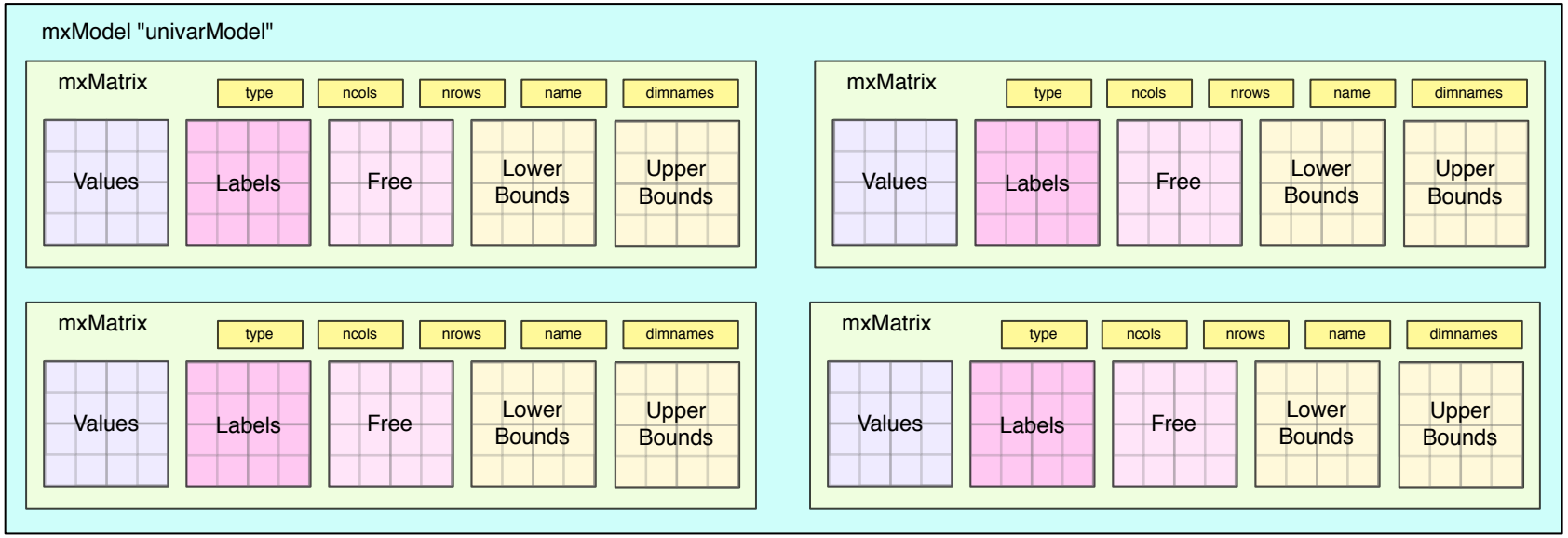


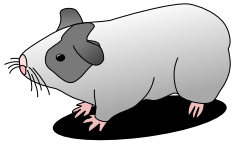


An MxMatrix Contains Values and Metainformation

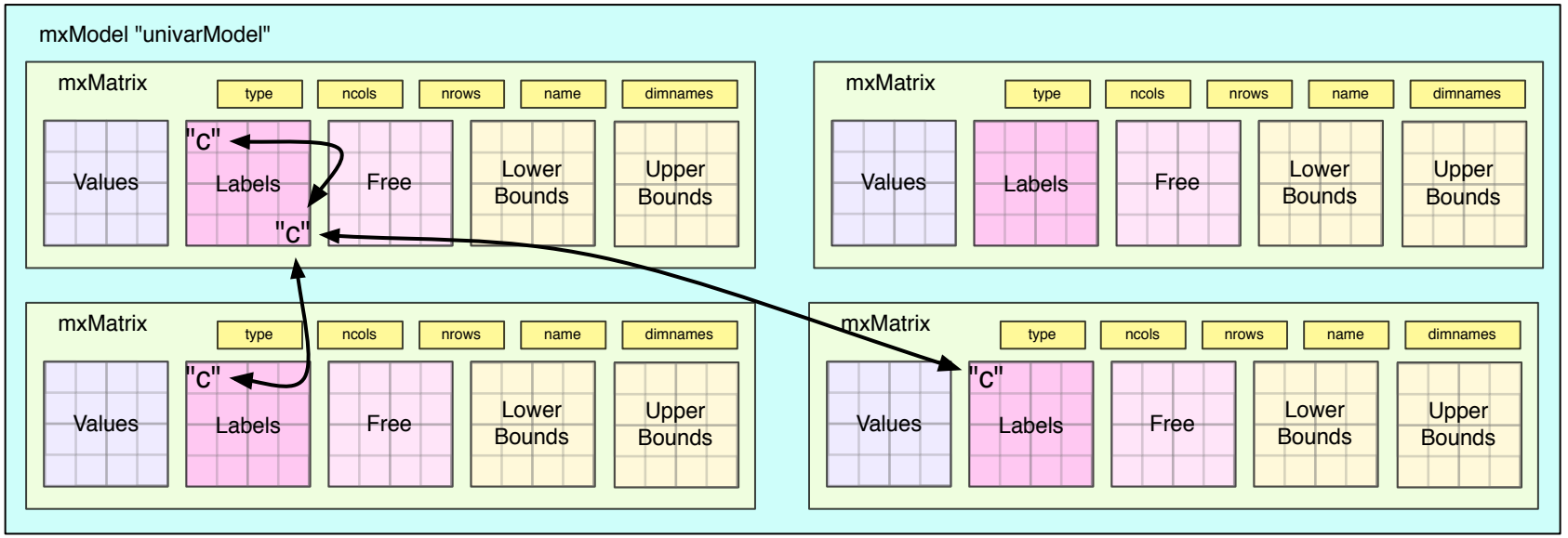


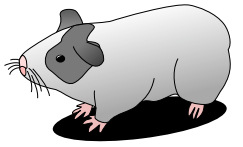
Many MxMatrices Can Be in an MxModel



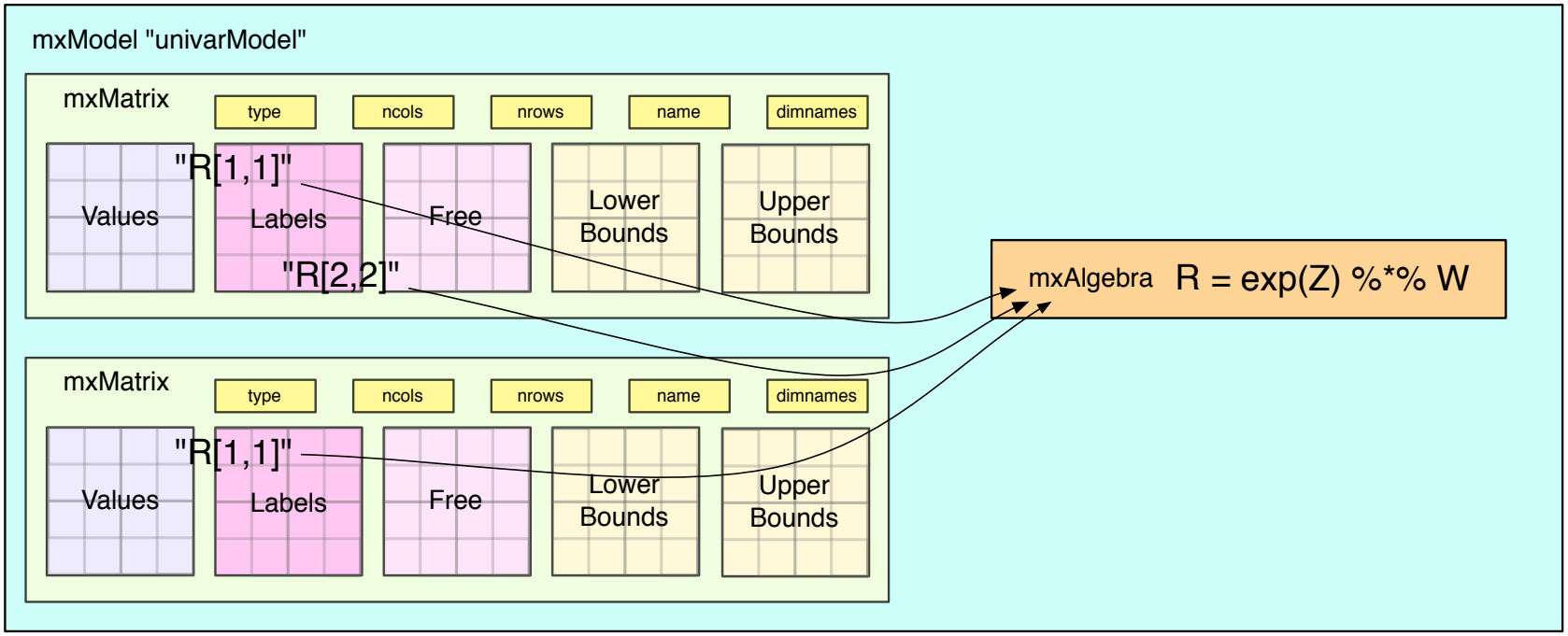


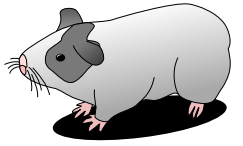
Labels Can Be Used For Equality Constraints



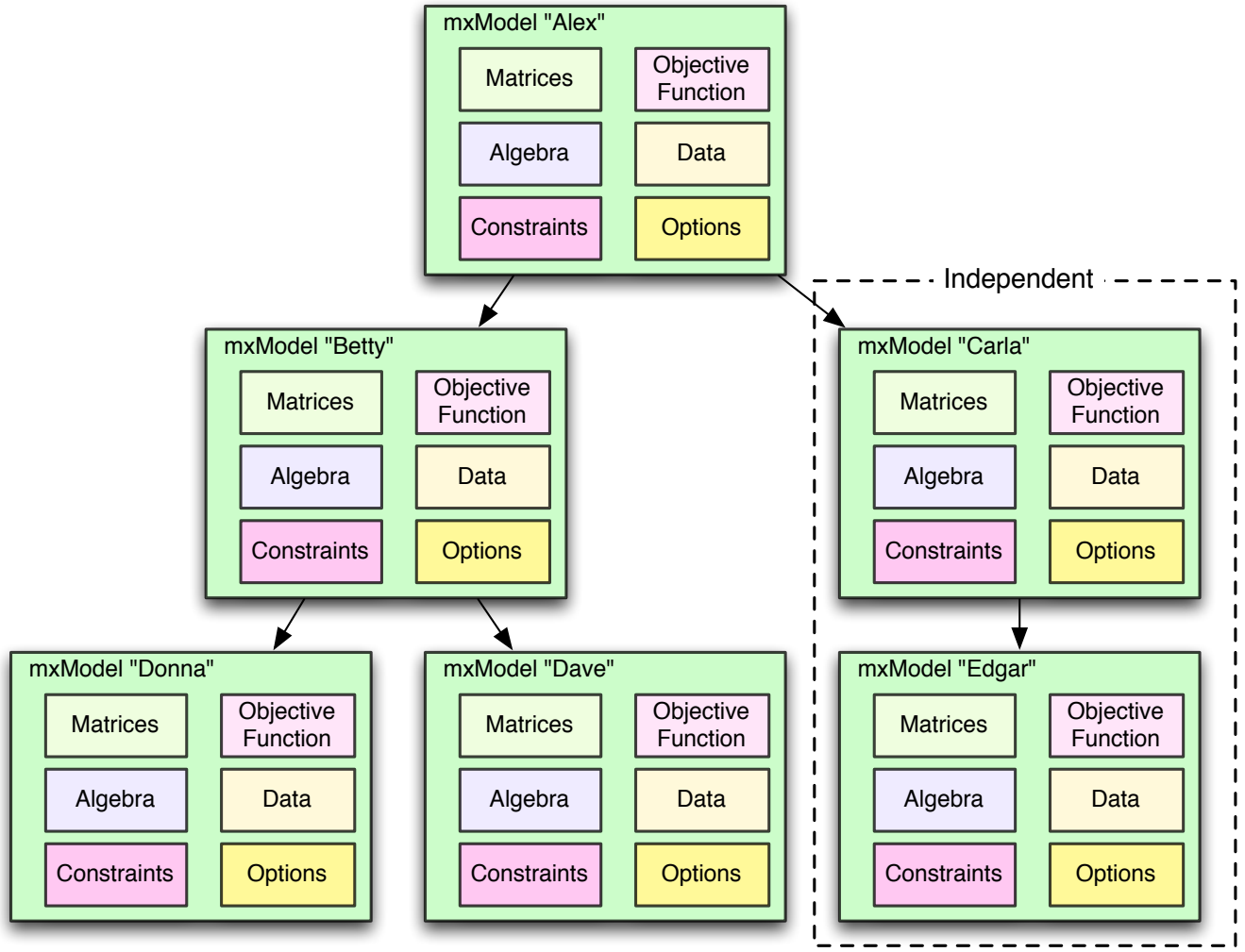


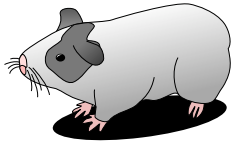
Labels Can Constrain to Algebraic Results



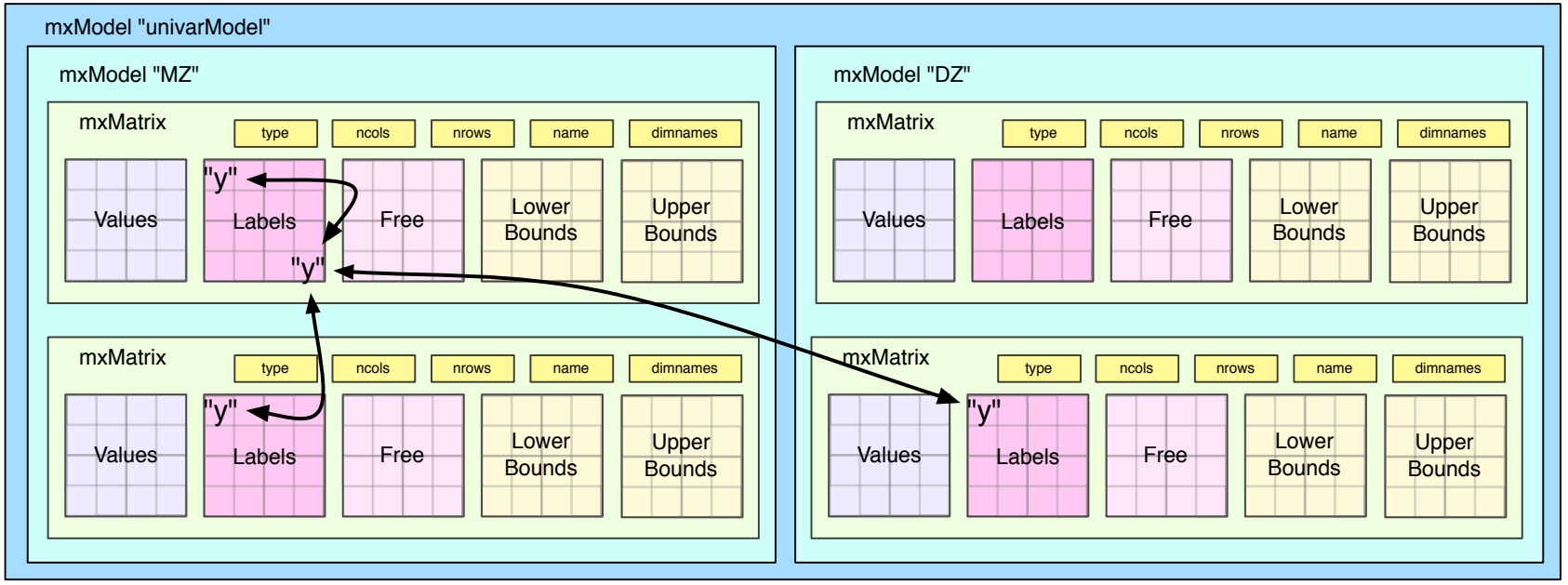


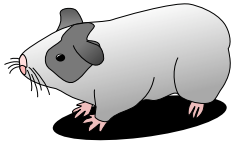
Models Can Be Hierarchically Structured





Equality Constraints between mxModels in a Hierarchy





Structure of a Univariate ACE mxModel

R & OpenMx General Usage

Case: Sensitive sensitive SENSITIVE

Comments: #Anything to the right of # on a line

Blank lines: are ignored

Keywords: gotta get them spelled and camelCased correctly!

OpenMx Matrix Types

>?mxMatrix

Type	Structure	Shape	Modifiable
Zero	Null (zeros)	Any	0
Unit	Unit (ones)	Any	0
Iden	Identity	Square	0
Diag	Diagonal	Square	r
SDiag	Subdiagonal	Square	r(r-1)/2
Stand	Standardized	Square	r(r-1)/2
Symm	Symmetric	Square	r(r+1)/2
Lower	Lower triangular	Square	r(r+1)/2
Full	Full	Any	r x c

Example Matrices I

Example Command	Free Matrix	Values
mxMatrix('Zero', 2, 3, free=T, name='A')	0 0 0 0 0 0	0 0 0 0 0 0
mxMatrix('Unit', 2, 3, free=T, name='B')	0 0 0 0 0 0	1 1 1 1 1 1
mxMatrix('Iden', 3, 3, free=T, name='C')	0 0 0 0 0 0 0 0 0	1 0 0 0 1 0 0 0 1
mxMatrix('Diag', 3, 3, free=T, values=c(1,2,3),name='D')	NA 0 0 0 NA 0 0 0 NA	1 0 0 0 2 0 0 0 3

NA denotes that a parameter is free and is not constrained to equal any other parameters. It is effectively a *missing label* for that parameter.

Example Matrices II

Example Command	Free Matrix	Starting Values
mxMatrix('Sdiag', 3, 3, free=T, values=c(3,4,5,6,7,8), name='E')	0 0 0 0 NA 0 0 0 NA NA 0 0 NA NA NA 0	0 0 0 0 3 0 0 0 4 6 0 0 5 7 8 0
mxMatrix('Stand', 3, 3, free=T, values= c(.6,.7,.8),name='B')	0 0 0 NA 0 0 NA NA 0	1 6 7 6 1 8 7 8 1
mxMatrix('Symm', 3, 3, free=T, name='C')	0 0 0 0 0 0 0 0 0	1 0 0 0 1 0 0 0 1
mxMatrix('Lower', 3, 3, free=T, values=c(1,2,3,4,5,6),name='D')	NA 0 0 NA NA 0 NA NA NA	1 0 0 2 4 0 3 5 6

Matrix Algebra
>?mxAlgebra

```
A <- mxMatrix('Full', nrow = 3, ncol = 3, values=2, name = 'A')

# Simple example: algebra B simply evaluates to the matrix A
B <- mxAlgebra(A, name = 'B')

# Compute A + B
C <- mxAlgebra(A + B, name = 'C')

# Compute sin(C)
D <- mxAlgebra(sin(C), name = 'D')

# Make a model and evaluate the mxAlgebra object 'D'
A <- mxMatrix('Full', nrow = 3, ncol = 3, values=2, name = 'A')
model <- mxModel('AlgebraExample', A, B, C, D )
fit   <- mxRun(model)
mxEval(D, fit)
```

Matrix Operators & Functions I

Operator name	R name	Conformability	(Classic Mx name)
Square Bracket Operator (element)	A[x,y]	--	\part(A,B)
Square Bracket Operator (row or col)	A[x,] or A[,y]	--	--
Square Bracket Operator (subrange)	A[x:y, w:z]	--	\part(A,B)
Transpose	t(A)	--	A'
Inversion	solve(A)	r=c	A~
Element powering	A ^ B	--	--
Matrix multiplication	A %*% B	$c_A=r_b$	A * B
Dot product	A * B	$r_A=r_B$ and $c_A=c_B$	A . B
Kronecker product	A %x% B	--	A @ B

Matrix Operators & Functions II

Operator name	R name	Conformability	(Classic Mx name)
Kronecker exponent	A %^% B	--	A ^ B
Quadratic product	A %&% B	$c_A=r_B=c_B$	A & B
Element division	A / B	$r_A=r_B$ and $c_A=c_B$	A % B
Addition	A + B	$r_A=r_B$ and $c_A=c_B$	A + B
Subtraction (binary)	A - B	$r_A=r_B$ and $c_A=c_B$	A - B
Subtraction (unary)	- A	--	- A
Horizontal adhesion	cbind(A,B,C)	$r_A=r_B$	A | B | C
Vertical adhesion	rbind(A,B,C)	$c_A=c_B$	A _ B _ C

Matrix Operators & Functions III

Operator name	R name	Conformability	(Classic Mx name)
Determinant	det(A)	--	\det(A)
Trace[1]	tr(A)	--	\tr(A)
Sum	sum(A,B,C)	--	\sum(A,B,C)
Product	prod(A,B,C)	--	\prod(A,B,C)
Maximum	max(A,B,C)	--	\max(A,B,C)
Minimum	min(A,B,C)	--	\min(A,B,C)
Absolute value	abs(A)	--	\abs(A)
Cosine	cos(A)	--	\cos(A)

Matrix Operators & Functions IV

Operator name	R name	Conformability	(Classic Mx name)
Hyperbolic cosine	cosh(A)	--	\cosh(A)
Sine	sin(A)	--	\sin(A)
Hyperbolic sine	sinh(A)	--	\sinh(A)
Tangent	tan(A)	--	\tan(A)
Hyperbolic tangent	tanh(A)	--	\tanh(A)
Element Exponent	exp(A)	--	\exp(A)
Element Natural Log	log(A)	--	\ln(A)
Element Square Root	sqrt(A)	--	\sqrt(A)

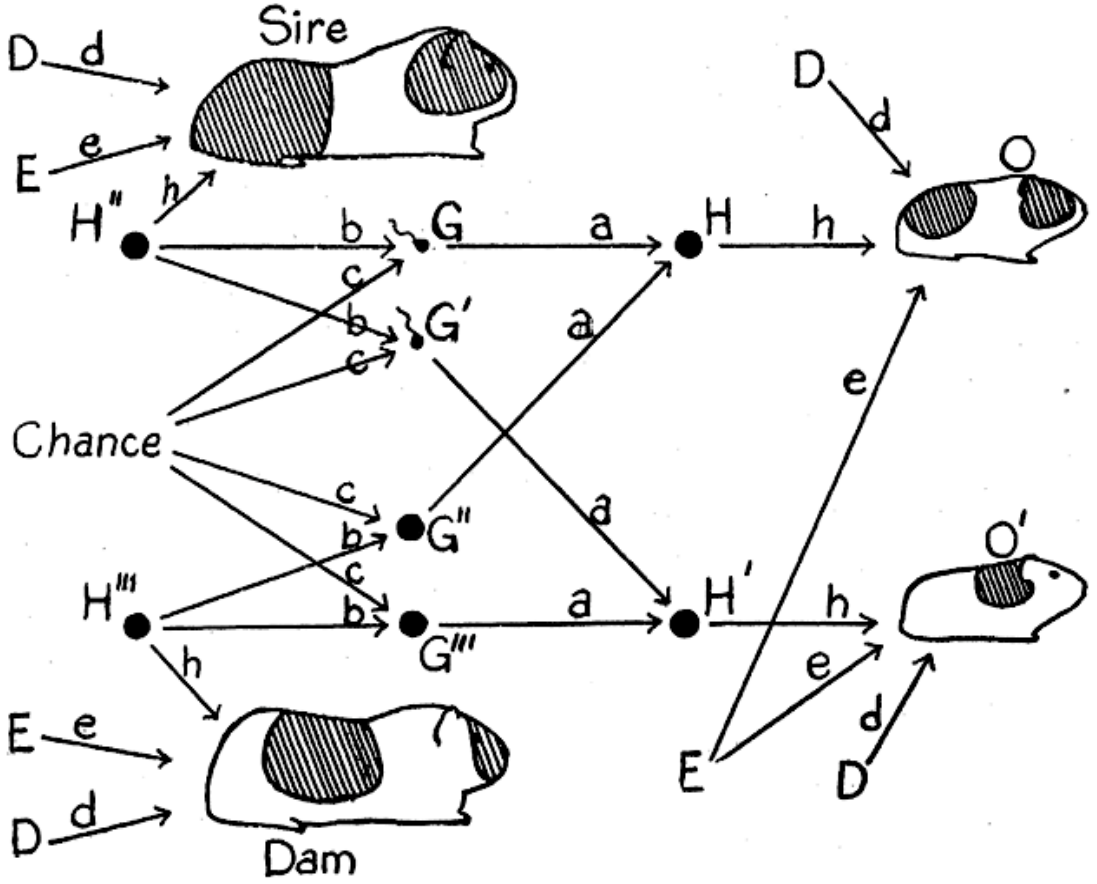
Matrix Operators & Functions V

Operator name	R name	Conformability	(Classic Mx name)
Strict half-vectorization	vechs(A)	--	--
Diagonal to vector	diag2vec(A)	--	\d2v(A)
Vector to diagonal	vec2diag(A)	$r_A=1$ or $c_A=1$	\v2d(A)
Multivariate normal integration	omxMnor(A)	--	\mnor(A)
All cells mvn integration	omxAllInt(A)	--	\allint(A)
Vectorize by row	rvectorize(A)	--	\m2v(A)
Vectorize by column	cvectorize(A)	--	\vec(A)
Real Eigenvectors	eigenvec(A)	--	\evec(A)

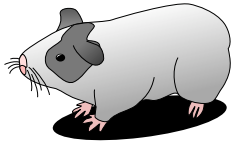
Matrix Operators & Functions VI

Operator name	R name	Conformability	(Classic Mx name)
Real Eigenvalues	eigenval(A)	--	\eval(A)
Imaginary Eigenvectors	ieigenvec(A)	--	\ivec(A)
Imaginary Eigenvalues	ieigenval(A)	--	\ival(A)

What's the Deal with the Guinea Pig?



The first published path diagram (Wright, 1920)



Thank you!

- NIH, NATO, IBG, Funding Bodies
- Fulker Eaves Kendler & Hewitt
- Twin Workshop Organizers, Faculty & Participants
- Study Participants