

lava REFERENCE CARD

Linear Latent Variable Models in R

MODEL BUILDING

- Initialize model (empty or multivariate regr. model)
- Initialize from list of regression models
- Add extra regression associations (slopes)
- Add correlation between residual terms
- Remove associations between variables
- Add variables
- Remove variables
- Code as latent (reverse with arg. `clear=TRUE`)
- Binary variables; `library(lava.tobit)`

```
m <- lvm(); m <- lvm(c(y1,y2)~x+z)
m <- lvm(list(y~x,y~z,...))
regression(m) <- c(y1,y3)~u
covariance(m) <- y1~y2+y3
cancel(m) <- ~y1+y2
addvar(m) <- ~y1+y2
kill(m) <- ~y1+y2
latent(m) <- ~y1+y2
binary(m) <- ~y1+y2
```

EQUALITY CONSTRAINTS

- **Intercepts**
 - Constrain intercepts to be identical
 - Simultaneously fix several intercepts
- **Variance/covariance parameters**
 - Fix variance term and covariance between residual to v1 resp. 1
 - Fix multiple variance parameters
 - Simultaneously fix several covariance parameters
- **Slope/regression parameters**
 - $y_1 = x + az + \dots$
 - $y_2 = x + bx + \dots$
 - $y_1 = x + \dots, \quad y_2 = az + \dots$
 - $y_i = ax + \dots$
 - Fix parameters defined by index (see `coef`)
 - Label all free parameters (see `multigroup`)
 - Remove linear constraints by fixing to NA (applies also to the `intercept` and `covariance` methods)
 - *Bracket notation.* Define intercept and variance of residual of y to 0 and 'v' and of x to 'a' and 1. And define $\mathbb{E}(y|x) = b \cdot x$.

```
intercept(m) <- c(y1,y2)~f(a)
intercept(m,~y1+y2) <- list("a",2)
```

```
covariance(m) <- y1~f(y1,v1)+f(y2,1)
covariance(m,~y1+y2) <- list("a",2)
covariance(m,c(y1,y2)~y2+y3) <- list(2,"a","b",1)
```

```
regression(m,c(y1,y2)~x+z) <- list(1,"a",2,"b")
```

```
regression(m,c(y1,y2)~x+z) <- list(1,"a")
```

```
regression(m) <- c(y1,y2,y3)~f(x,a)
```

```
parfix(m,c(3,4,12)) <- list(1,"a",2)
```

```
m <- baptize(m)
```

```
regression(m) <- c(y1,y2)~f(x,NA)
```

```
regression(m) <- y[0:v]~f(x[a,1],b)
```

SIMULATION

- Simulate 100 observations from model `m`
- Simulate with the slope-parameter of x on y set to -2, and intercept of y to 1 (see `coef`)
- Define conditional distribution
- Predefined distributions
- Define functional form of predictor on response

```
sim(m,100,...)
```

```
sim(m,100,p=c("y"=1, "y<-x"=-2),...)
```

```
distribution(m,~y1+y2) <-
```

```
function(n,mu,var,...) ...
```

```
binomial.lvm,,uniform.lvm,normal.lvm,poisson.lvm
```

```
functional(m,y~x) <- funct
```

NON-LINEAR CONSTRAINTS

- Non-linear parameter constraints
- Non-linear regression (covariate x)
- Add extra parameters to model
- Add predictor/exogenous variable to model
- Random slopes (x name of covariate)
- Print non-linear constraints

```
constrain(m,psi~beta+gamma) <- funct
constrain(m,psi~beta+x) <- funct
parameter(m) <- ~beta+gamma
exogenous(m) <- ~x1+x2
regression(m) <- y1~f(eta,x)
constrain(m)
```

MODEL INSPECTION

- Examine parameter constraints
- Extract variable names
- Submodel (see also `measurement`)
- List parameter names
- Parents and children of nodes (union)
- Extract (directed) pathways between variables

```
intercept,covariance,regression,constrain
exogenous,endogenous,latent,manifest,vars
subset(m,~y1+y2+eta+x)
coef(m,mean=TRUE,labels=FALSE,...)
parents(m,~y1+y2);children(m,~x1+x2)
path(m,y~x)
```

PLOTTING

- Plot method (`lvm` and `lvmfit`)
- Change appearance of nodes
- Change label and appearance of edges
- Change labels of nodes (e.g. math expressions)
- Extract graphNEL object (`library(Rgraphviz)`)

```
plot(m,labels=TRUE,...)
nodecolor(m,~y1+x,labcol=c("red","blue"),
border,lwd=2, ...) <- c("blue","red")
edgelabels(m,y~x+z,col,...) <- expression(rho)
labels(m) <- c(eta=expression(eta))
Graph(m)
```

STATISTICAL INFERENCE

- Estimate parameters (default MLE)
- Estimate multigroup model (default MLE)
- Estimate under MAR assumption
- Likelihood ratio tests vs. saturated model
- Likelihood ratio tests
- Model indices based on score tests (or Wald tests)
- Identify empirical equivalent models
- Calculate indirect and total effects of x on y
- Non-linear constraints and approx. std.errors
- Mixtures of LLVM; `library(lava.mixture)`
- Extract various likelihood summaries
- Clustered correlated data
- Robust standard errors
- Test for linearity; `library(gof)`
- Non-parametric bootstrap
- Likelihood-based confidence limits

```
e <- estimate(m,data,estimator,...)
estimate(list(m,...),list(data,...),...)
estimate(m,data,missing=TRUE,...)
compare(e)
compare(e1,e2,e3,...)
modelsearch(e,...)
equivalence(e,y~x,k=1,...)
effects(e, y~x)
constraints(e)
mixture(list(m1,m2),data)
coef, score, information, logLik, AIC, gof
estimate(m,data,cluster="id",...)
coef(e,type="robust")
cumres(e,...)
bootstrap(e,R=100,...)
confint(e,idx,profile=TRUE,...)
```

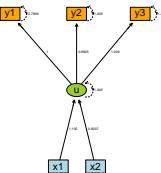
EXAMPLES

Linear Latent Variable Models in R

STRUCTURAL EQUATION MODEL

MIMIC model

```
> m <- lvm(c(y1,y2,y3)~u)
> regression(m) <- u ~ x1+x2
> latent(m) <- ~ u
> d <- sim(m,100)
> e <- estimate(m,d)
> plot(e)
```



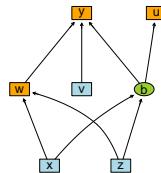
RANDOM REGRESSION

Random slopes allowing for unbalanced designs

```
> m <- lvm(c(y1,y2,y3)~f(eta,1))
> regression(m,c(y1,y2,y3)~u) <- list("x1","x2","x3")
> intercept(m, "y1+y2+y3") <- list("mu")
> covariance(m, "y1+y2+y3") <- list("v","v","v")
> latent(m) <- ~u+eta
> estimate(m,data,missing=TRUE)
```

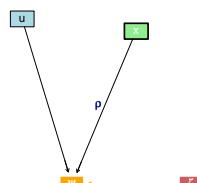
GRAPHICS I

```
> m <- lvm(list(y ~ b+v+w, c(b,w) ~ x+z, u ~ b))
> latent(m) <- ~b
> plot(m)
```



GRAPHICS II

```
> m <- lvm(y~x+z+u)
> labels(m) <- c(y=expression(psi), z=expression(zeta))
> nodecolor(m, "y+z+x", border=c("white","white","black"),
+   labcol="white", lwd=c(0,0,5)) <-
+   c("orange","indianred","lightgreen")
> edgelabels(m,y~z+x, cex=c(2,3), col=c("orange","black"),
+   labcol="darkblue",lwd=c(3,1)) <- expression(phi,rho)
> plot(m,layoutType="circo")
```



INSTRUMENTAL VARIABLE

IV estimator (not available with e.g. non-recursive structures)

```
> estimate(m,data,estimator="IV")
```

SIMULATION

Weibull with exponential distributed censoring

```
> m <- lvm(y~x1+x2+x3)
> distribution(m, "y") <- weibull.lvm(shape=0.5,cens=rexp)
> distribution(m, "x3") <- binomial.lvm()
> d <- sim(m,100)
```

MULTIVARIATE PROBIT

```
> m <- lvm(c(y1,y2)~f(x,b)+f(z,b))
> binary(m) <- ~y1+y2
> covariance(m) <- y1~y2
> estimate(m,data,control=list(trace=1))
```

MULTIGROUP ANALYSIS I

$$\log L(\theta|d) = \sum_i \log L_i(\theta|d_i)$$

```
> estimate(list(m1,m2,m3),list(d1,d2,d3))
```

INDIRECT EFFECTS. TOBIT/PROBIT MODEL

$$\mathbb{E}(y | x, z) = a(x + z)$$

```
> m <- lvm(list(y~z+x,z~x))
> d <- transform(sim(m,100),z=factor(z>0),y=Surv(ifelse(y<1,y,1),y<1))
> e <- estimate(m,d)
> effects(e,y~x)
```

NON-LINEAR REGRESSION

Bi-variate non-linear regression with random intercept. Estimated via Fischer scoring

```
> m0 <- lvm(c(y1,y2)~f(x,0)+f(eta,1))
> latent(m0) <- ~eta
> covariance(m0) <- c(y1,y2) ~ f(0.01)
> covariance(m0) <- c(eta) ~ f(0.01)
> d <- sim(m0,50)[,manifest(m0)]
> d <- transform(d,
+   y1=y1+pnorm(2*x),
+   y2=y2+pnorm(2*x))
> m <- m0
> parameter(m) <- ~nu+alpha+xi
> intercept(m) <- c(y1,y2) ~ f(mu)
> covariance(m) <- c(y1,y2) ~ f(v)
> covariance(m) <- eta ~ f(zeta)
> constrain(m, mu ~ x + alpha + nu + xi) <- function(x) pnorm(x[1]*x[2]+x[4]) + x[3]
> e <- estimate(m,d,control=list(trace=1,method="NR",gamma=0.99))
```