

lava REFERENCE CARD

Linear Latent Variable Models in R

MODEL BUILDING

• Initialize model (empty or multivariate regr. model)	<code>m <- lvm(); m <- lvm(c(y1,y2)~x+z)</code>
• Initialize from list of regression models	<code>m <- lvm(list(y~x,y~z,...))</code>
• Add extra regression associations (slopes)	<code>regression(m) <- c(y1,y3)~u</code>
• Add correlation between residual terms	<code>covariance(m) <- y1~y2+y3</code>
• Remove associations between variables	<code>cancel(m) <- ~y1+y2</code>
• Add variables	<code>addvar(m) <- ~y1+y2</code>
• Remove variables	<code>kill(m) <- ~y1+y2</code>
• Code as latent (reverse with arg. <code>clear=TRUE</code>)	<code>latent(m) <- ~y1+y2</code>
• Binary variables; library(lava.tobit)	<code>binary(m) <- ~y1+y2</code>

EQUALITY CONSTRAINTS

• Intercepts	
◦ Constrain intercepts to be identical	<code>intercept(m) <- c(y1,y2)~f(a)</code>
◦ Simultaneously fix several intercepts	<code>intercept(m,~y1+y2) <- list("a",2)</code>
• Variance/covariance parameters	
◦ Fix variance term and covariance between residual to v1 resp. 1	<code>covariance(m) <- y1~f(y1,v1)+f(y2,1)</code>
◦ Fix multiple variance parameters	<code>covariance(m,~y1+y2) <- list("a",2)</code>
◦ Simultaneously fix several covariance parameters	<code>covariance(m,c(y1,y2)~y2+y3) <- list(2,"a","b",1)</code>
• Slope/regression parameters	
◦ $y_1 = x + az + \dots$ $y_2 = x + bx + \dots$	<code>regression(m,c(y1,y2)~x+z) <- list(1,"a",2,"b")</code>
◦ $y_1 = x + \dots$, $y_2 = az + \dots$	<code>regression(m,c(y1,y2)~x+z) <- list(1,"a")</code>
◦ $y_i = ax + \dots$	<code>regression(m) <- c(y1,y2,y3)~f(x,a)</code>
• Fix parameters defined by index (see <code>coef</code>)	<code>parfix(m,c(3,4,12)) <- list(1,"a",2)</code>
• Label all free parameters (see <code>multigroup</code>)	<code>m <- baptize(m)</code>
• Remove linear constraints by fixing to NA (applies also to the <code>intercept</code> and <code>covariance</code> methods)	<code>regression(m) <- c(y1,y2)~f(x,NA)</code>
• <i>Bracket notation.</i> Define intercept and variance of residual of y to 0 and 'v' and of x to 'a' and 1. And define $\mathbb{E}(y x) = b \cdot x$.	<code>regression(m) <- y[0:v]~f(x[a,1],b)</code>

SIMULATION

• Simulate 100 observations from model <code>m</code>	<code>sim(m,100,...)</code>
• Simulate with the slope-parameter of x on y set to -2 , and intercept of y to 1 (see <code>coef</code>)	<code>sim(m,100,p=c("y"=1, "y<-x"=-2),...)</code>
• Define conditional distribution	<code>distribution(m,~y1+y2) <- function(n,mu,var,...) ...</code>
◦ Predefined distributions	<code>binomial.lvm,,uniform.lvm,normal.lvm,poisson.lvm</code>
• Define functional form of predictor on response	<code>functional(m,y~x) <- funct</code>

NON-LINEAR CONSTRAINTS

• Non-linear parameter constraints	<code>constrain(m,psi~beta+gamma) <- funct</code>
• Non-linear regression (covariate x)	<code>constrain(m,psi~beta+x) <- funct</code>
• Add extra parameters to model	<code>parameter(m) <- ~beta+gamma</code>
• Add predictor/exogenous variable to model	<code>exogenous(m) <- ~x1+x2</code>
• Random slopes (x name of covariate)	<code>regression(m) <- y1~f(eta,x)</code>
• Print non-linear constraints	<code>constrain(m)</code>

MODEL INSPECTION

• Examine parameter constraints	<code>intercept,covariance,regression,constrain</code>
• Extract variable names	<code>exogenous,endogenous,latent,manifest,vars</code>
• Submodel (see also <code>measurement</code>)	<code>subset(m,~y1+y2+eta+x)</code>
• List parameter names	<code>coef(m,mean=TRUE,labels=FALSE,...)</code>
• Parents and children of nodes (union))	<code>parents(m,~y1+y2);children(m,~x1+x2)</code>
• Extract (directed) pathways between variables	<code>path(m,y~x)</code>

PLOTTING

• Plot method (<code>lvm</code> and <code>lvmfit</code>)	<code>plot(m,labels=TRUE,...)</code>
• Change appearance of nodes	<code>nodecolor(m,~y1+x,labcol=c("red","blue"),border,lwd=2,...) <- c("blue","red")</code>
• Change label and appearance of edges	<code>edgelabels(m,y~x+z,col,...) <- expression(rho)</code>
• Change labels of nodes (e.g. math expressions)	<code>labels(m) <- c(eta=expression(eta))</code>
• Extract <code>graphNEL</code> object (library(<code>Rgraphviz</code>))	<code>Graph(m)</code>

STATISTICAL INFERENCE

• Estimate parameters (default MLE)	<code>e <- estimate(m,data,estimator,...)</code>
• Estimate multigroup model (default MLE)	<code>estimate(list(m,...),list(data,...),...)</code>
• Estimate under MAR assumption	<code>estimate(m,data,missing=TRUE,...)</code>
• Likelihood ratio tests vs. saturated model	<code>compare(e)</code>
• Likelihood ratio tests	<code>compare(e1,e2,e3,...)</code>
• Model indices based on score tests (or Wald tests)	<code>modelsearch(e,...)</code>
• Identify empirical equivalent models	<code>equivalence(e,y~x,k=1,...)</code>
• Calculate indirect and total effects of x on y	<code>effects(e, y~x)</code>
• Non-linear constraints and approx. std.errors	<code>constraints(e)</code>
• Mixtures of LLVM; library(lava.mixture)	<code>mixture(list(m1,m2),data)</code>
• Extract various likelihood summaries	<code>coef,score,information,logLik,AIC,gof</code>
• Clustered correlated data	<code>estimate(m,data,cluster="id",...)</code>
• Robust standard errors	<code>coef(e,type="robust")</code>
• Test for linearity; library(<code>gof</code>)	<code>cumres(e,...)</code>
• Non-parametric bootstrap	<code>bootstrap(e,R=100,...)</code>
• Likelihood-based confidence limits	<code>confint(e,idx,profile=TRUE,...)</code>

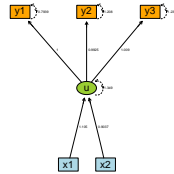
EXAMPLES

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)
```



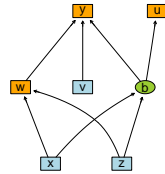
RANDOM REGRESSION

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)
```

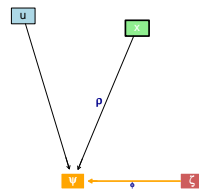
GRAPHICS I

```
> 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))
```