

## Autoregressive model of order $p$ (AR( $p$ ))

WE ARE EXPERIMENTING CURRENTLY WITH A NEW (JOINT) PRIOR FOR THE PACF's...

### Parametrization

The autoregressive model of order  $p$  (AR1( $p$ )) for the Gaussian vector  $\mathbf{x} = (x_1, \dots, x_n)$  is defined as (in obvious notation)

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + \dots + \phi_p x_{t-p} + \epsilon_t$$

for  $t = p, \dots, n$ , and where the innovation process  $\{\epsilon_t\}$  has fixed precision.

The AR( $p$ ) process has an awkward parameterisation, as there are severe non-linear constraints on the  $\phi$ -parameters for it to define a stationary model. Therefore we re-parameterized using the partial autocorrelation autocorrelation function,  $\{\psi_k, k = 1, \dots, p\}$ , where  $|\psi_k| < 1$  for all  $k$ <sup>1</sup> and its *marginal (NOT conditional) precision*  $\tau$ . Furthermore, the joint distribution for  $\{x_t, t = 1, \dots, p\}$ , is set to the stationary distribution for the process, hence there are no boundary issues.

### Hyperparameters

The marginal precision parameter  $\tau$  is represented as

$$\theta_1 = \log(\tau)$$

and the prior for the marginal precision is defined on  $\theta_1$ . The partial autocorrelation function  $\{\psi_k\}$  is represented

$$\psi_k = 2 \frac{\exp(\theta_{k+1})}{1 + \exp(\theta_{k+1})} - 1$$

for  $k = 1, \dots, p$ . The prior for  $\{\theta_{k+1}, k = 1, \dots, p\}$  is *defined* to be multivariate normal with mean  $\mu$  and precision matrix  $Q$ .

### Specification

The AR( $p$ ) model is specified inside the `f()` function as

```
f(<whatever>, model="ar", order=<p>, hyper = <hyper>)
```

The option `order` ( $> 0$ ) is required. The multivariate normal prior for  $\{\theta_{k+1}, k = 1, \dots, p\}$ , is specified as the parameters to the prior for  $\theta_2$  (the first pacf-parameter), and the parameters to the multivariate normal prior (`mvnorm`), is `c( $\mu, Q$ )`; see the example below.

### Hyperparameter spesification and default values

**hyper**

**theta1**

**hyperid** 15001

**name** log precision

**short.name** prec

**initial** 4

**fixed** FALSE

**prior** pc.prec

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<sup>1</sup>See for example [https://en.wikipedia.org/wiki/Partial\\_autocorrelation\\_function](https://en.wikipedia.org/wiki/Partial_autocorrelation_function). For  $p = 1$ , then  $\psi_1 = \phi_1$ , and for  $p = 2$ , then  $\psi_1 = \phi_1/(1 - \phi_2)$  and  $\psi_2 = \phi_2$ .

```

    param 3 0.01
    to.theta function(x) log(x)
    from.theta function(x) exp(x)
theta2
    hyperid 15002
    name pacf1
    short.name pacf1
    initial 1
    fixed FALSE
    prior pc.rho0
    param 0.5 0.5
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta3
    hyperid 15003
    name pacf2
    short.name pacf2
    initial 0
    fixed FALSE
    prior pc.rho0
    param 0.5 0.4
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta4
    hyperid 15004
    name pacf3
    short.name pacf3
    initial 0
    fixed FALSE
    prior pc.rho0
    param 0.5 0.3
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta5
    hyperid 15005
    name pacf4
    short.name pacf4
    initial 0
    fixed FALSE
    prior pc.rho0
    param 0.5 0.2
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta6

```

```

hyperid 15006
name pacf5
short.name pacf5
initial 0
fixed FALSE
prior pc.rho0
param 0.5 0.1
to.theta function(x) log((1+x)/(1-x))
from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta7
hyperid 15007
name pacf6
short.name pacf6
initial 0
fixed FALSE
prior pc.rho0
param 0.5 0.1
to.theta function(x) log((1+x)/(1-x))
from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta8
hyperid 15008
name pacf7
short.name pacf7
initial 0
fixed FALSE
prior pc.rho0
param 0.5 0.1
to.theta function(x) log((1+x)/(1-x))
from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta9
hyperid 15009
name pacf8
short.name pacf8
initial 0
fixed FALSE
prior pc.rho0
param 0.5 0.1
to.theta function(x) log((1+x)/(1-x))
from.theta function(x) 2*exp(x)/(1+exp(x))-1
theta10
hyperid 15010
name pacf9
short.name pacf9
initial 0

```

```

    fixed FALSE
    prior pc.rho0
    param 0.5 0.1
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1
  theta11
    hyperid 15011
    name pacf10
    short.name pacf10
    initial 0
    fixed FALSE
    prior pc.rho0
    param 0.5 0.1
    to.theta function(x) log((1+x)/(1-x))
    from.theta function(x) 2*exp(x)/(1+exp(x))-1

  constr FALSE

  nrow.ncol FALSE

  augmented FALSE

  aug.factor 1

  aug.constr

  n.div.by

  n.required FALSE

  set.default.values FALSE

  status experimental

  pdf ar

```

## Example

```

n = 100L
p = 2L
pacf = runif(p)
phi = inla.ar.pacf2phi(pacf)
y = arima.sim(n, model = list(ar = phi)) +
  rnorm(n, sd=sd(y)/100.0)
idx = 1L:n

param.prec = c(1, 0.01)
param.psi.mean = rep(0, p)
param.psi.prec = 0.15 * diag(p)
param.psi = c(param.psi.mean, param.psi.prec)

r = inla(y ~ -1 + f(
  idx, model='ar',

```

```

order = p,
hyper = list(
  ## marginal precision
  prec = list(param = param.prec),
  ## the parameters for the joint normal prior for the
  ## transformed pacf's, goes here.
  pacf1 = list(param = param.psi)),
family = "gaussian",
data = data.frame(y, idx))

## we will now estimate the posterior marginals of the phi-parameters
## using the (experimental) function 'inla.hyperpar.sampler', which
## creates samples from the approximated joint distribution for the
## hyperparameters.
nsamples = 100000
pacfs = inla.hyperpar.sampler(nsamples, r)[, 3L:(3L+(p-1L))]
phis = apply(pacfs, 1L, inla.ar.pacf2phi)
for(i in 1:p) {
  inla.dev.new()
  plot(density(phis[i, ]), main = paste("phi", i, sep=""))
  abline(v = phi[i])
}

```

## Notes

- The functions `inla.ar.pacf2phi` and `inla.ar.phi2pacf` converts from the  $\phi$ -parameters to the  $\psi$ -parameters, using the Durbin-Levinson recursions. These can also be used to compute, the marginal posteriors of the  $\phi$ -parameters from an approximation of the joint of the  $\phi$ -parameters; see the example for a simulation based approach.
- Currently, the order  $p$  is limited to 10. If this creates a problem, let us know.
- If some of the  $\psi_k$ -parameters are fixed, and  $k < p$ , then the marginal (log-)likelihood is wrong; The joint normal prior for all the  $p$   $\psi$ -parameters is used and not the conditional normal prior condition on the fixed  $\psi_k$ -parameters. If this creates a problem, let us know.
- The prior specification for the multivariate normal is a bit awkward. Hopefully, we will come up with a better way to do this in the future.
- This model is currently marked as experimental.