

# LSmodel - Large Scale Model Class

**LSmodel** is a class for representation and management of Large Scale (LS) models. LS model is described as a set of submodels together with description of submodels mutual interconnections and submodels interconnections with external inputs and outputs.

Signal interconnections is name based, i.e. to define that outputs and inputs of certain submodels are connected requires to give them the same names. Submodels are internally represented as state-space models. However any model type, which can be converted by SS command, can be supplied as submodel and original model is stored in LSmodel class along with its state-space conversion.

LS model is created from a set of submodels with named inputs and outputs (at least interconnection signals should be named), a set of summator created for example by SUMBLK commands and string cell arrays defining external inputs and outputs (see **LSmodel\_example.m**). The model can be later modified by adding new submodels, removing submodels, adding/removing external inputs/outputs.

LS model supports specification of different signal types for each signal

Signal Type	Abbreviation	Channel
Manipulated	MV	Input
Measured Disturbances	MD	Input
Unmeasured Disturbances	UD	Input
Measured Outputs	MO	Output
Unmeasured Outputs	UO	Output
Internal Signal	X	--

and specification of signal limits (min/max values, min/max slopes,...). This information is later used for estimator and/or controller design.

**LSmodel** has methods for structured model order reduction, decomposition of subsystems into groups for distributed control/estimation and merging of information from multiple models into single one.

Model structure can be plotted by overloaded plot command and model analysis can be done by many standard overloaded functions (see below).

State-space model of full **LSmodel** can be obtained by SS method. Parts of model can be obtained either for selected inputs and outputs or by extracting group of subsystems, where grouping information may be a result of built-in decomposition method.

## Methods

```

LSmodel      - constructor, compatible with Matlab connect function

add_mod      - adds submodel to LS model
add_sum      - adds summator (creates new internal signal)
add_ext_inp  - adds external input to LS model
add_ext_out  - adds external output from LS model
rem_mod      - removes submodel from LS model
rem_sum      - removes summator
rem_ext_inp  - removes external input
rem_ext_out  - removes external output

set_sig_type - signal types according to the MPC toolbox
set_sig_lim  - set signal limits (min/max, delta min/max)
set_sig_data - assigns (user) data structure to selected signal(s)

select       - extracts part of the model for selected inputs and
               outputs
group        - extracts subsystems belonging to given group
squeeze      - remove unused external inputs/outputs and unconnected
               submodels

struct_red   - structured model order reduction
merge        - merging of ARX models of different structure
freq_uncert  - return frequency uncertainty for ARX model
eps          - epsilon decomposition
bbd          - Border Block Diagonal decomposition

display      - presents the model content and shows the numbering of
               subsystems, summators, inputs and outputs
n            - returns total order (sum of subsystems order)
orders       - returns subsystems orders
plot         - plots interaction between subsystems

```

### Overloaded functions

```

dcgain, pole, zero, impulse, step, bode, nyquist, pzmap, iopzmap,
ss, ...

```

### Internal model structure

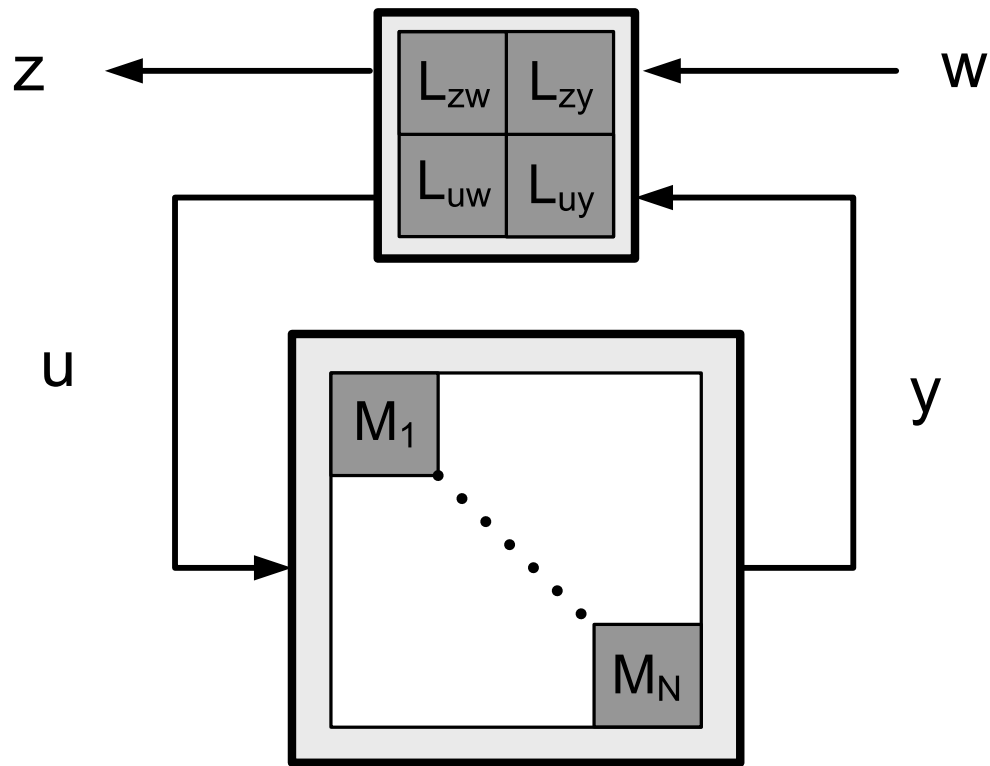
Internal model structure can be seen in the following figure. The signal names are:

```

w ... external inputs to LS model
z ... external outputs from LS model
u ... aggregated inputs to submodels
y ... aggregated outputs from submodels

```

Submodels are stored in cell array `M` as state-space models. The original models supplied by the user are stored in cell array `Morig`. External model inputs are stored in string cell array `Wnames` and outputs in `Znames`. Static interconnections matrices `Lzw`, `Lzy`, `Luw`, `Luy` represent submodels mutual interconnections and submodel interconnections with external inputs and outputs. They are automatically computed after each model modification.




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## LSmodel Constructor

LSMODEL( X1,...,Xn, INPUT\_NAMES, OUTPUT\_NAMES ) constructs large scale model by specifying a set of submodels, summators and a list of external input and output names. Internal connections are automatically created by matching signal names. Xi are models or summators (single or in a cell array). INPUT\_NAMES and OUTPUT\_NAMES are cell arrays of strings with external input and output names. Summators can be created by command SUMBLK. Examples:

```
mod = LSmodel(M,sum',{'fuel','demand'},{'pressure','flow'});
```

```
mod = LSmodel(M1,M2,M3,M4,sum1,sum2',{'fuel','demand'},{'pressure','flow'});
```

M is cell array of models (ss,tf,...) with named inputs and outputs. SUM is cell array of summators created by SUMBLK.

**Constructor is compatible with standard CONNECT function.** It is also possible to construct the model by using CONNECT compatible numeric indexing of inputs and outputs (see help on CONNECT). However, name based signal referencing will be preferred as numeric indexing may be confusing for large scale models.

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## Remove Model

REM\_MOD(OBJ,PAR) removes model from large scale system. PAR is a vector of indexes or string cell array of model names to be deleted. (model indexes are shown by display function)

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## Remove Summator

REM\_SUM(OBJ,PAR) removes summator from large scale system. PAR is the index or the name of the summator to be deleted. Summator indexes are shown by display function.

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## Add Model

ADD\_MOD(OBJ,NEWM) adds new model NEWM to large scale model class and connects it according to the input / output names. NEWM can be a cell array of models.

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## Add Summator

ADD\_SUM(OBJ,NEWS) adds new summator to the model and connects it according the input/output names. Numeric based interconnection is not possible. NEWS can be an array of summators.

Summator can be created by SUMBLK function.

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## Remove External Input

REM\_EXT\_INP(OBJ,PAR) Removes external input. PAR can be input index or its NAME.

---

## Add External Input

ADD\_EXT\_INP(OBJ,NAME) adds external input named NAME.

---

## Remove External Output

REM\_EXT\_OUT(OBJ,PAR) Removes external output. PAR can be output index or its NAME.

---

## Add External Output

ADD\_EXT\_OUT(OBJ,NAME) adds external output named NAME.

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## Display Object

DISPLAY Displays basic information about LSmodel.

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## Return Global Model Order

N=N(OBJ) returns global model order as a sum of subsystem orders.

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## Return Orders of Subsystems

N=ORDERS(OBJ) returns orders of subsystems in array

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## Get Global SS Model

MOD=SS(obj) returns state space model of the whole model.

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## Epsilon Decomposition

EPS(OBJ,N\_TARGET) finds \epsilon decomposition of water network model after leafs condensation. Decomposes the network to N\_TARGET subnetworks.

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## Set Signal Type

SET\_SIG\_TYPE(OBJ,NAMES,TYPE) - set type of signals for MPC design. Signal types are compatible with MPC toolbox:

Signal Type	Abbreviation	Channel
Manipulated	MV	Input
Measured Disturbances	MD	Input
Unmeasured Disturbances	UD	Input
Measured Outputs	MO	Output
Unmeasured Outputs	UO	Output
Internal Signal	X	--

MODEL is name or index of submodel. SIGNALS is a cell of input names or their indexes and TYPE is abbreviation of signal type (MV,MD,UD).

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## Set Signal Limits

SET\_SIG\_LIM(OBJ,NAMES,MIN,MAX,DMIN,DMAX,SMIN,SMAX) sets MIN / MAX limits on absolute values, sets DMIN / DMAX limits on speed of change and sets SMIN / SMAX soft limits on absolute values. Limits are applied to signal(s) specified by name in NAMES

SET\_SIG\_LIM(OBJ,NAMES,MIN,MAX,DMIN,DMAX) sets MIN / MAX limits on absolute values and sets DMIN / DMAX limits on speed of change.

SET\_SIG\_LIM(OBJ,NAMES,MIN,MAX) sets MIN / MAX limits on absolute values.

SET\_SIG\_LIM(OBJ,NAMES) removes all limits (sets them to inf).

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## Set Signal Data

SET\_SIG\_DATA(OBJ,NAMES,DATA) assigns user data structure to signal(s) specified in NAMES.

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## Master Connection Matrix

[MZW,MZY,MUW,MUY] = MASTERL(OBJ) returns aggregated matrices indicating connection between external inputs, submodels and external outputs.

---

## Extract model part for given external inputs and outputs

NOBJ = SELECT(OBJ,INPUTS,OUTPUTS) extracts part of the model for selected inputs and outputs. Submodels, which are not conotrllable or observable from selected inputs and outputs are not included in extracted model. INPUTS and OUTPUTS can be cell array of inputs/outputs signal names or their numerical index (see DISP).

NOBJ = SELECT(OBJ,INPUTS,OUTPUTS,OPT) parameter OPT controls, which submodels are kept and which are removed from final model:

```
'io' ..... eliminates submodels, which are not controllable and/or
              observable
'full' ..... keep all submodels
'ss' ..... (default) eliminates submodels which are not
              controllable and observable are removed
```

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### Extract submodels belonging to given group

`NOBJ = GROUP(OBJ,GR_IND)` extracts parts of LS model, where submodels belong to the group(s) specified in vector `GR_IND`.

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### Remove unused external inputs/outputs and submodels

`NOBJ = SQUEEZE(OBJ)` removes external inputs and outputs, which are not connected to any submodels and also removes submodels which are not connected anything.

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### Structured Model Order Reduction

`OBJ = STRUCT_RED(OBJ,N_TARGET) ...`

`OBJ = STRUCT_RED(OBJ,N_TARGET,METHOD) ...`

Based on: Henrik Sandberg, Richard M. Murray: "Model reduction of interconnected linear systems". Optimal Control, Applications and Methods, Special Issue on Directions, Applications, and Methods in Robust Control, 30:3, pp. 225–245, May/June 2009.

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### Merging of uncertain models

`MERGE(OBJ,MOD,NEW_MOD,TARGET_NB,TARGET_NA)` updates uncertain submodel by new model. Updated submodel is determined by its index or its name in variable `MOD` and new model is specified by `NEW_MOD`. This function supports so far only ARX models (IDARX or IDPOLY classes of submodels).

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### Frequency uncertainty of ARX model

`[MEAN,VAR] = FREQ_UNCERT(OBJ,MOD,W)` returns mean value and variation for model `MOD` on frequencies `W`. This function supports so far only ARX models (IDARX or IDPOLY classes of submodels).