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# SaTool

A Tool for Structural Analysis of Automated Systems

*An introduction to the use of SaTool*

*Socrates Lecture by Mogens Blanke*
*Monday July 5th 2004*

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## Introduction

- Why structural analysis
- Answers the questions:
  - Is the system controllable
  - Can faults in the system be identified
  - Can the system handle faults smartly
    - Reconfiguration
    - Shutdown
    - Graceful degradation
- How
  - Analysis of the structure graph of the system



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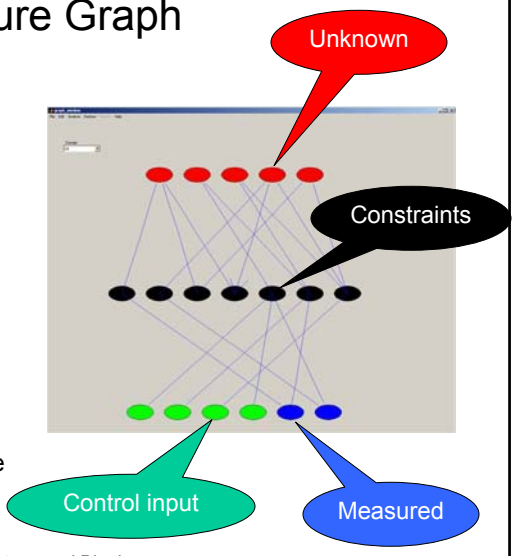
## Structure Graph

**Structural analysis**

A graph-based technique where principal relations between variables express the system's properties. Measured and controlled quantities in the system are related to variables through functional relations, which need not be explicitly stated. The user specifies a list of these relations that together describe the functionality of the system considered. A list of such variables and functional relations constitute the system's structure graph.

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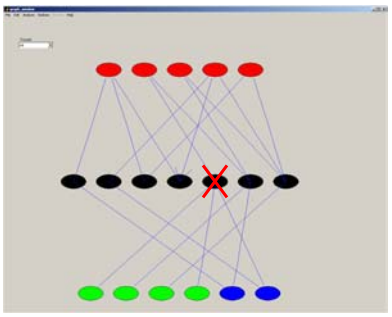
## A Fault is a Violation of a Constraint

**Faults**

Normal operation means all functional relations are intact for the system. Should faults occur, one or more functional relations cease to be valid. In the structure graph, one or more nodes of the graph will disappear when a fault occurs.



**SaTool** is an implementation of structural analysis theory. It will analyze a structure graph and provide knowledge about fundamental properties of the system in normal and faulty conditions.

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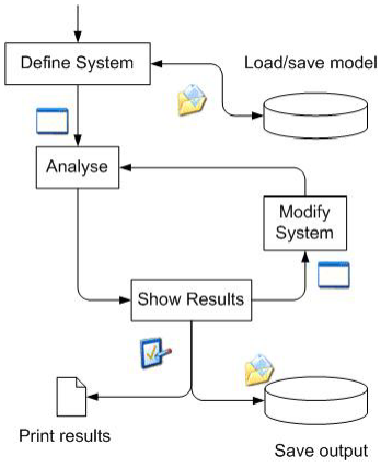
## Development cycle using SaTool




SaTool supports:

- Define system structure
- Analyse structure graph
- Show results
- Modify system
- Load/save models
- Save/print results



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## SaTool – A tool for Structural Analysis

### Features

- Matlab ® based (version 6.5 or later)
- Graphical representation of structure as a graph
- Easy point and click manipulation of system structure
- Matching by ranking
- Backtracing
  - Recursive algorithm

*Matlab ® is a trademark of the Math Works Inc. USA.*



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## Installation and startup

Prerequisites:
- SaTool, requires Matlab ® version 6.5 or later.

Installation:
- Unzip the SaTool.zip file
- Place the files in a folder eg. c:\mymatlab\satool
- Add the folder to the MatLab path, in MatLab type:
  - addpath('c:\mymatlab\satool')

Startup:
- type constraint_editor to start the program

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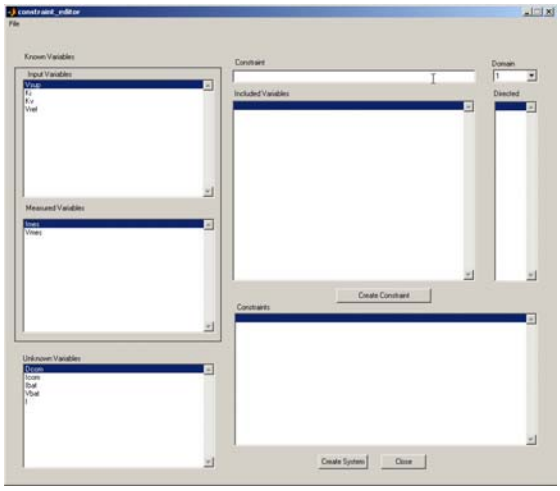
## The Constraint Editor

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# Example

Battery Charger

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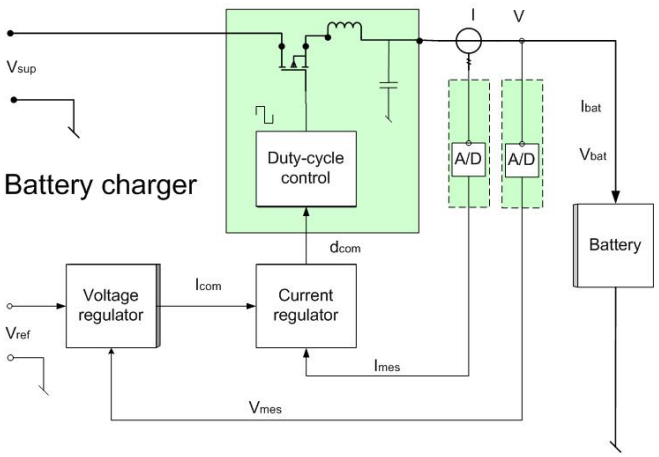
## Battery Charger



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## Identify Variables

| | |
|---|---|
| $d$ | power stage duty cycle |
| $d_{com}$ | duty cycle command |
| $I$ | output current |
| $I_{bat}$ | battery charge current |
| $I_{com}$ | command to current coltrol block |
| $I_{mes}$ | measured output current |
| $k_i$ | gain in current control block |
| $k_v$ | gain in voltage control block |

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## Identify Variables (2)

| | |
|---|---|
| $R_{bat}$ | equivalent battery resistance |
| $V_{bat}$ | battery voltage |
| $V_{mes}$ | measured output voltage |
| $V_{ref}$ | reference voltage to voltage control block |
| $V_{sup}$ | supply voltage |

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## Identify Constraints

Constraints:

| | | |
|---|---|---|
| *Cpsmc* | Power stage current: | $I = d * \max(V_{\sup} - V_{bat}, 0)$ |
| *Ccc* | Current control: | $d = f_i(I_{com} - I_{mes}, t) \simeq k_i(I_{com} - I_{mes})$ |
| *Cvc* | Voltage control: | $I_{com} = f_v(V_{ref} - V_{mes}, t) \simeq k_v(V_{ref} - V_{mes})$ |
| *Ccm* | Current measurement: | $I_{mes} = I$ |
| *Cvm* | Voltage measurement: | $V_{mes} = V_{bat}$ |
| *Ch* | Harness: | $I_{bat} = I$ |
| *Cd* | Power stage: | $d = d_{com}$ |
| *Dbv* | Battery voltage: | $\frac{d}{dt}V_{bat} = R_{bat}(V, I)I_{bat}(t),$ <br> $R_{bat}(V, I) = known$ |

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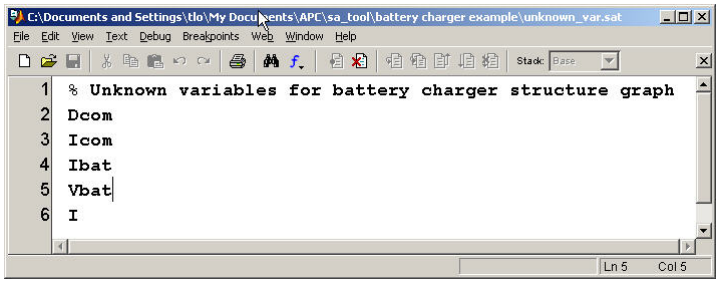
## Load variables

- Create a text file with variable names
  - One for each type of variable
  - Save the files as eg. 'unknown_var.sat'

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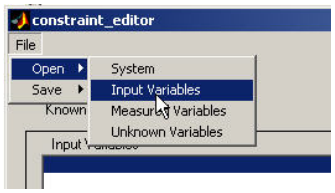
## Loading variables (2)

- Start the constraint editor with input parameters:
  - type “constraint_editor(‘file1’,’file2’,’file3’)”
  - Then the variables are loaded from start
- Start the constraint editor without input parameters:
  - type “constraint_editor”
  - load the variables using the file menu

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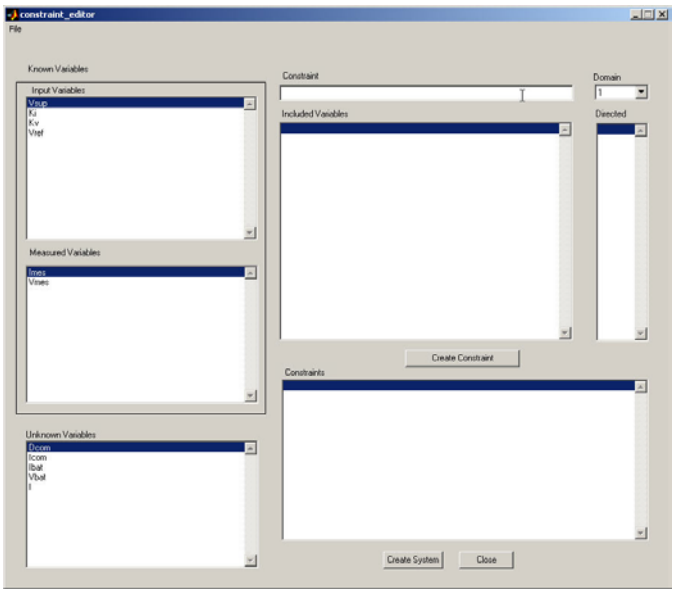


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## Create the structure model

- Create a constraint by:
  - Select variables
  - Set variables as directed if necessary
  - Give the constraint a name
  - Set the domain
  - Press **Create Constraint**
- Repeat until all constraints are generated
- Press **Create System**

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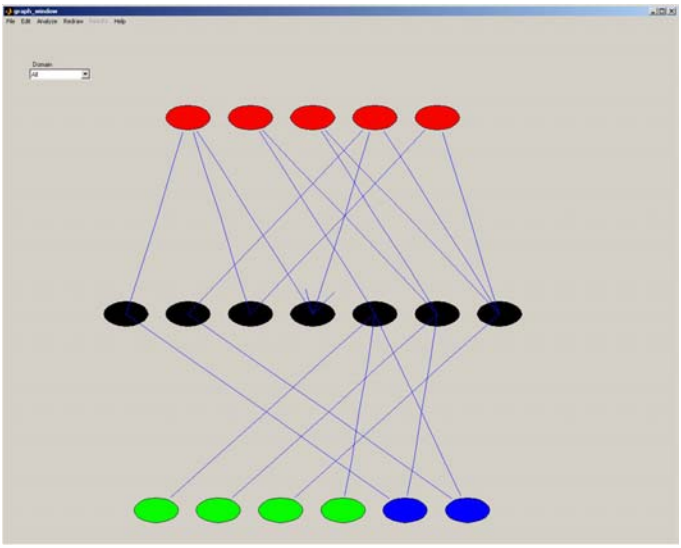

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## Colors on the graph

- RED: Unknown Variables
- BLACK: Constraints
- GREEN: Input Variables
- BLUE: Measured Variables



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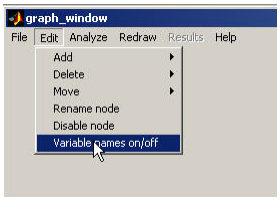
## Variable names on/off

- Select **Edit -> Variable Names on/off**



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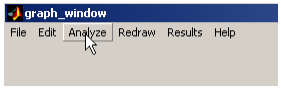
## Performing the analysis

- In the menu press **Analyze**




- The matching is marked on the graph
- The **Results** menu point is activated
- A drop down menu called **Parity Equation** appears

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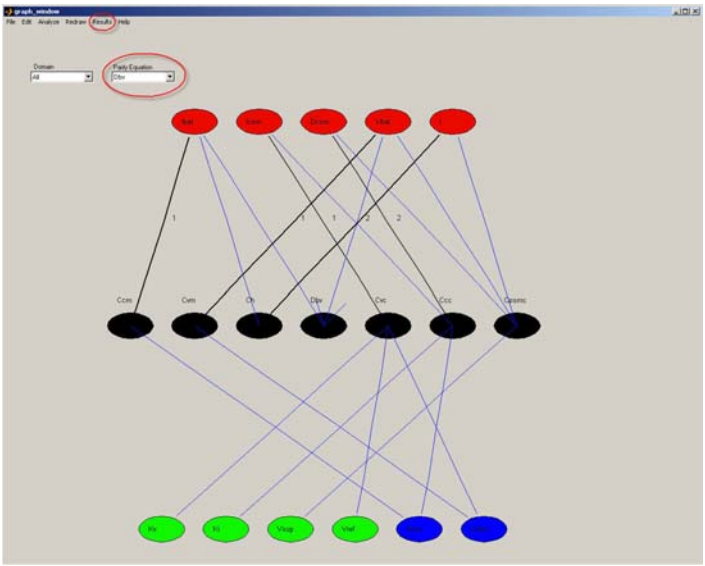

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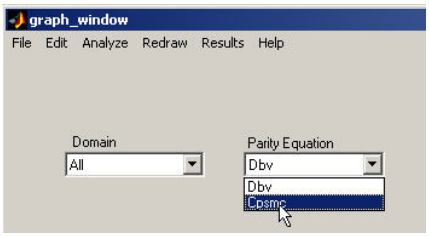
## View the results (1)

- Select a parity equation from the dropdown menu




- Result
  - Parity Relation
  - Included variables yellow

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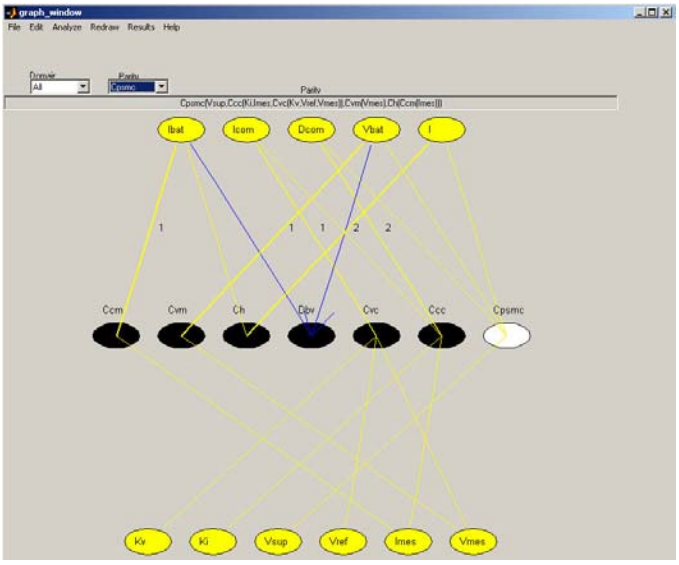


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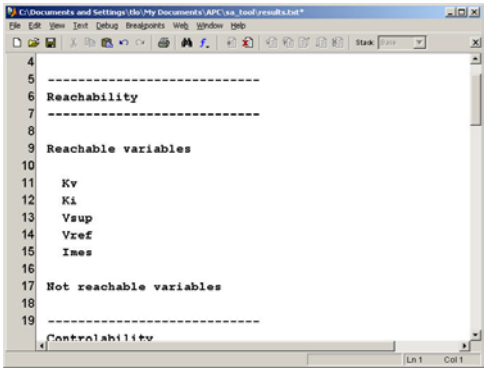
## Viewing the results

- Press **Results:**
  - The matlab editor opens and shows the results in a text file



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## Results

- Reachability
  - Can I reach the unknown variables from the known variables
  - Requirement for observability
- Controllability
  - Can I reach the unknown variables from the input variables
- Parity relations
  - Which relations exists
- Detectability
  - Which faults can be detected with the found parity relations
- Isolability
  - Which faults can be isolated with the found parity relations



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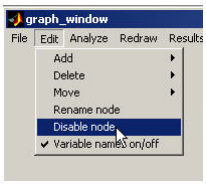
## Investigate the effect of a structural fault

- Faults can be modeled by disabling nodes
  - Select **Disable Node** from the edit menu




  - Click on a node to disable it
  - Perform a new analysis
- The result shows if the system can be reconfigured in case of faults

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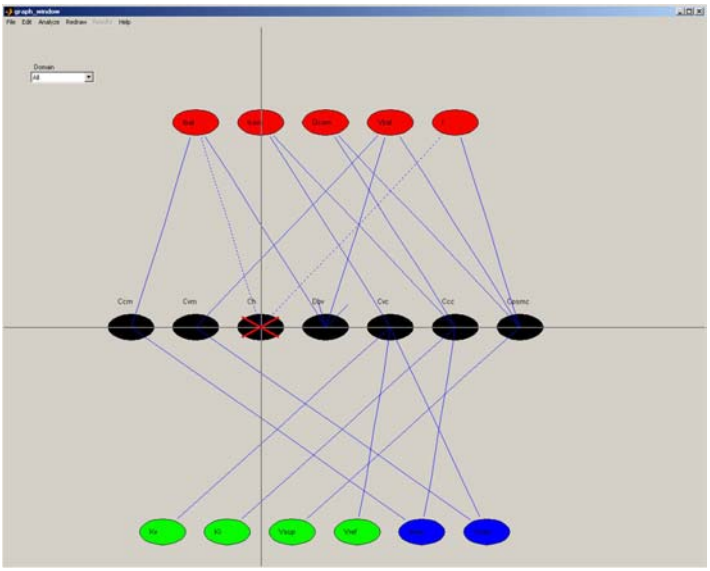

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## Effect of fault

- Rerun the analysis
- Investigate the new result
  - Can the system still be matched
  - Is there any parity relations
  - Is the system still
    - Controllable
    - Reachable
  - Are faults still
    - Detectable
    - Isolable

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## Acknowledgements


- Prof. Marcel Staroswiecki (Lille) was the originator of Structural Analysis (1984). Development and application was pursued by himself and co-workers and co-workers, in particular Dr. P. Declerk and Dr. J. P. Cassar since 1991.
- Ranking and closed loop issues were contributed by Prof. Jan Lunze (Bochum) and M.Sc Thomas Steffen (2001-03).
- Dr. R. Izadi-Zamanabadi (Aalborg) wrote a version of the matching function in 2002 – the version implemented in SaTool represent major revisions contributed by Torsten Lorentzen
- SaTool tool was developed at DTU (Lyngby) by M.Sc. Torsten Lorentzen (2002-04). The proficient implementation of the entire SaTool is due to his skills and GUI features of Matlab ® version 6.5.
- American Power Conversion (DK branch in Kolding) is acknowledged for sponsoring the implementation of SaTool and for the industrial touch the tool has achieved


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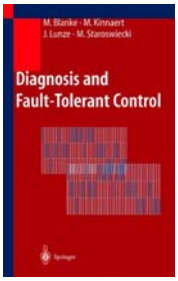
## References to Structural Analysis

*The original references to Structural Analysis:*

*Staroswiecki, M.: Structural Analysis of Complex Systems (1984): RAIRO Automatique, **18** (2), pp 147-59 (French language).*

*Staroswiecki M. and P. Declerck (1989): Analytical Redundancy in Non-linear Interconnected Systems by Means of Structural Analysis. Proc. IFAC AIPAC'89 (Nantes) vol. 2, pp 23-27. (English language)*




*A digested description with recent amendments is found in the book:*

*Diagnosis and Fault-tolerant Control.*
*By M. Blanke, M. Kinnaert, J. Lunze and M. Staroswiecki.*

*Springer, 2003. 565 pp. ISBN 3-540-01056-4.*

*See also the references herein.*

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## References to SaTool

*Lorentzen, T. and M. Blanke: SaTool users manual. Technical Report, Automation at Ørsted-DTU, Technical University of Denmark, Build. 326, DK 2800 Kgs. Lyngby, Denmark, Apr. 2004. 55 pp.*

*Lorentzen, T. and M. Blanke: SaTool software reference. Technical Report, Automation at Ørsted-DTU, Technical University of Denmark, Build. 326, DK 2800 Kgs. Lyngby, Denmark, Apr. 2004. 76 pp.*

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