TOPFARM
A Wind Farm Optimization Framework

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System Engineering Workshop
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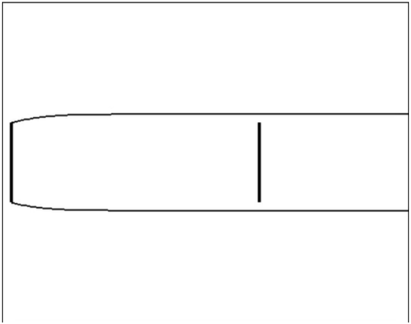
Motivation

- Aero-Elastic Design Section is principally interested in wind turbine design
- Wind turbines design depends of inflow inputs (upstream wakes)
- Dynamic Wake Meandering (DWM) can calculate wake induced loads
- Other wake models can calculate power production (e.g. FUGA)
- How can we introduce these tools together into wind farm design?



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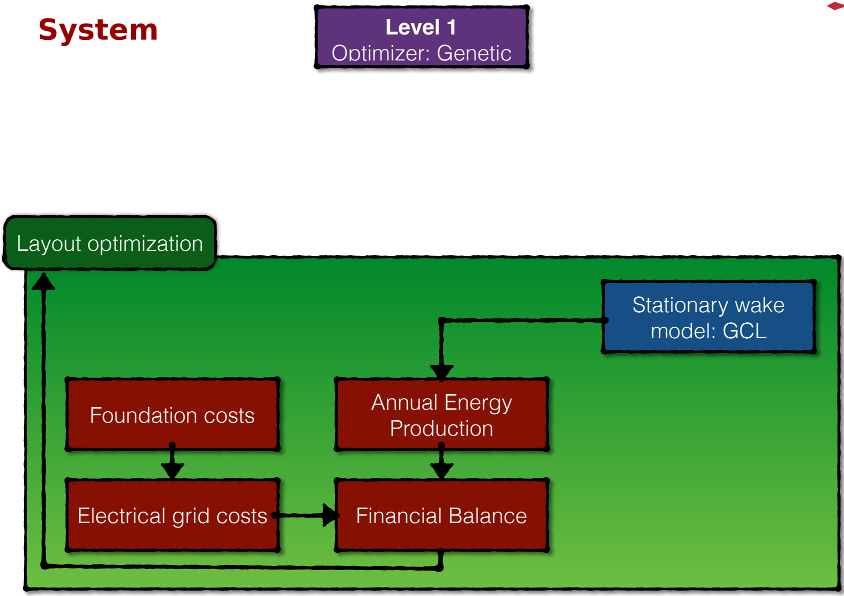
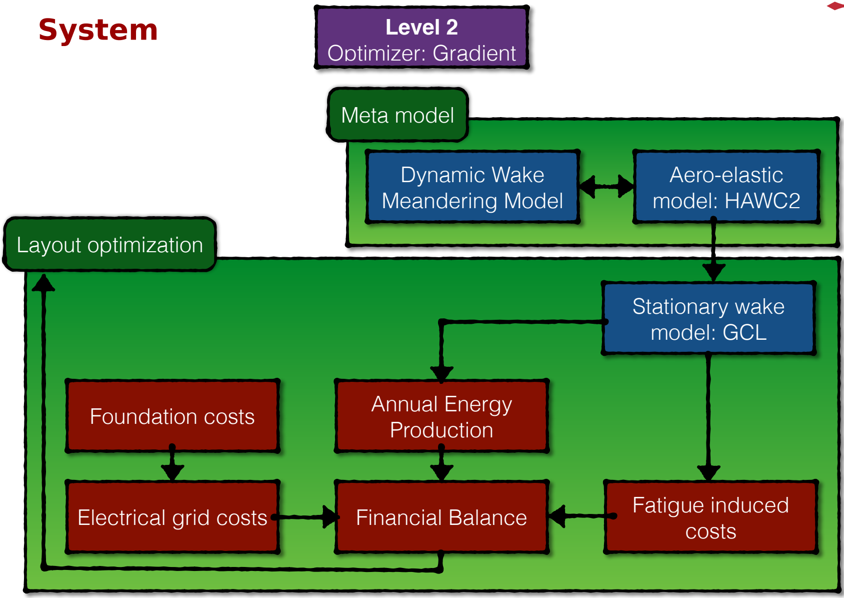
TOPFARM EU-FP6

- TOPFARM = Topology OPtimization of wind FARM
- EU-FP6 Funded project 2006-2010
- Multi-fidelity framework for wind farm layout optimization
- Optimization from the wind farm developer perspective
- Objective function is the wind farm lifetime financial balance
- The cost models take into account:
  - Wake effects on power production
  - Wake effects on wind turbines components fatigue
  - Offshore foundation costs
  - Electrical grid cabling
  - Financial parameters

System

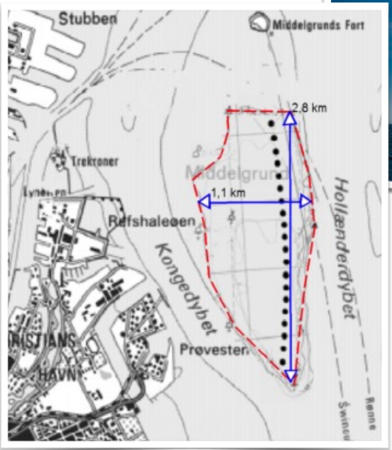

Level 1
Optimizer: Genetic
Layout optimization
Stationary wake model: GCL
Foundation costs
Annual Energy Production
Electrical grid costs
Financial Balance

System



Level 2
Optimizer: Gradient
Meta model
Dynamic Wake Meandering Model
Aero-elastic model: HAWC2
Layout optimization
Stationary wake model: GCL
Foundation costs
Annual Energy Production
Electrical grid costs
Financial Balance
Fatigue induced costs

The Middelgrunden test case



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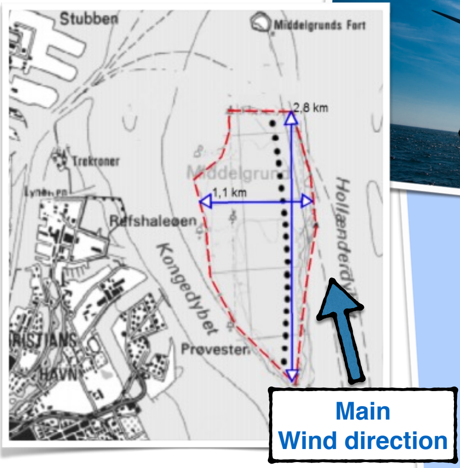
The Middelgrunden test case



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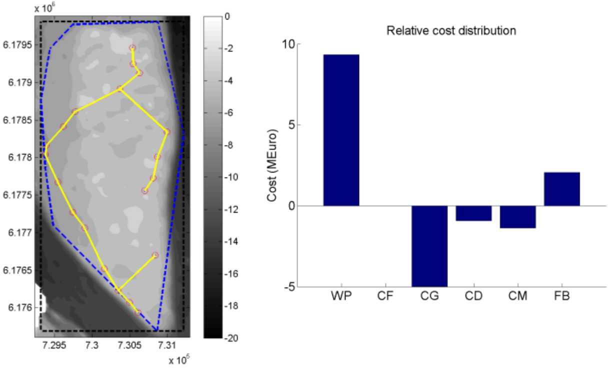
The Middelgrunden test case

Middelgrunden after iterations: 1000 SGA + 20 SLP

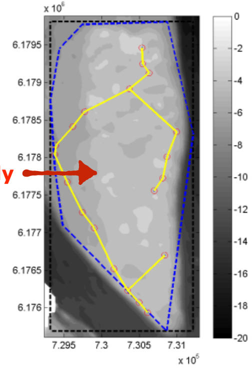


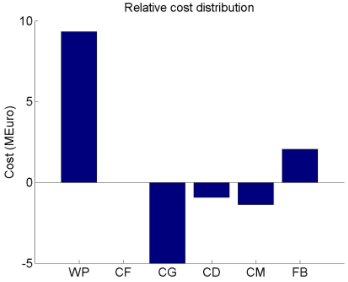
Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).

The Middelgrunden test case

Middelgrunden after iterations: 1000 SGA + 20 SLP

Disclaimer: We are not suggesting that building this ugly wind farm is a good idea





Optimum wind farm layout (left) and financial balance cost distribution relative to baseline design (right).

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Feedbacks from the wind industry

- Nice to be able to estimate the wake induced fatigue
- Workflow not ready for a push-of-a-button holistic solution
- Multi-disciplinary design tools are difficult to be use in large "bureaucratic" organizations.
- Integrate the expert(s) opinion(s) within optimization loop, somehow
- Wish for an open framework, to use their own cost & physical models they already have experience with.

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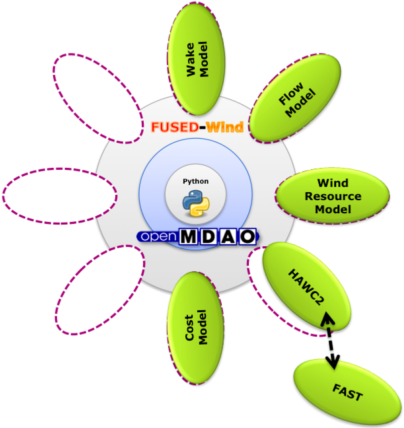
Connecting All Wind Energy Models in a Worflow

- Collaborative effort between DTU and NREL to create a **F**ramework for **U**nified **S**ystem **E**ngineering and **D**esigned of **Wind** energy plants.
- Based on OpenMDAO, a python based Open source framework for **M**ulti-**D**isciplinary **A**nalysis and **O**ptimization.



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Main Ideas

- Framework based on **FUSED-Wind**
- Use **WAsP & WRF** engine to calculate accurate local wind resources
- Multi-fidelity wake model based on DTU's wind farm flow model family
- 3rd level of fidelity: running the whole wind farm with dynamic wake models (**DWM & AL/LES**)
- More advanced multi-fidelity optimization strategy
- Higher degree of parallelization
- Expert driven iterative design process
- GUI connected to **WAsP**

DTU's Wind Farm Flow Model Family

Engineering	CFD
G.C.Larsen	EllipSys3D RANS Actuator Disc
N.O.Jensen	EllipSys3D LES Actuator Disc
FUGA	EllipSys3D LES Actuator Line
DWM	

Should they compete or collaborate?

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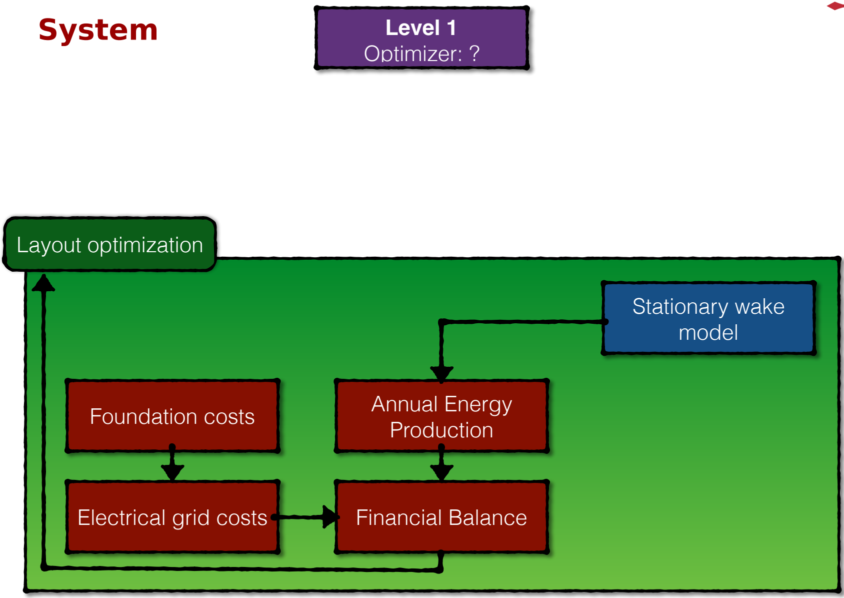
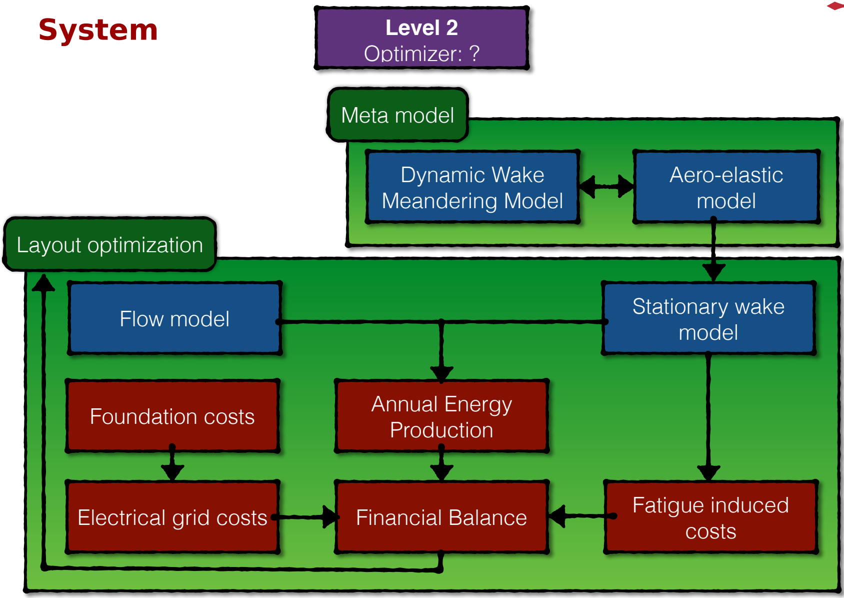
System

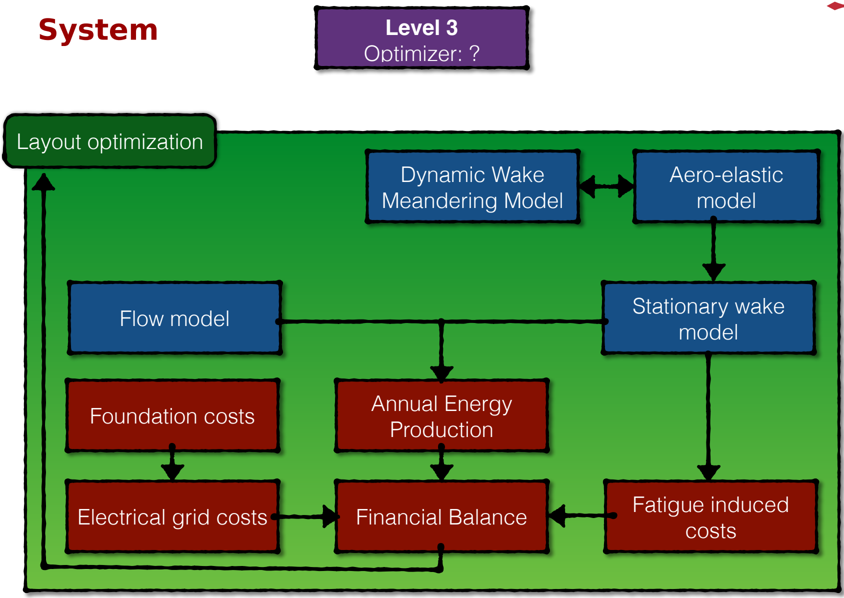

Level 1
Optimizer: ?
Layout optimization
Stationary wake model
Foundation costs
Annual Energy Production
Electrical grid costs
Financial Balance

System



Level 2
Optimizer: ?
Meta model
Dynamic Wake Meandering Model
Aero-elastic model
Layout optimization
Flow model
Stationary wake model
Foundation costs
Annual Energy Production
Electrical grid costs
Financial Balance
Fatigue induced costs

System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Optimizer: ?
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Aero-elastic model
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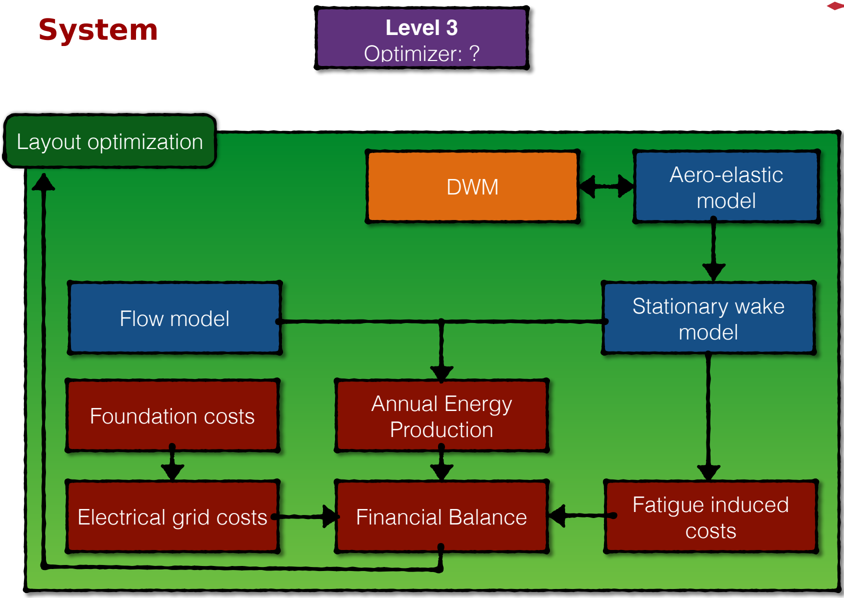
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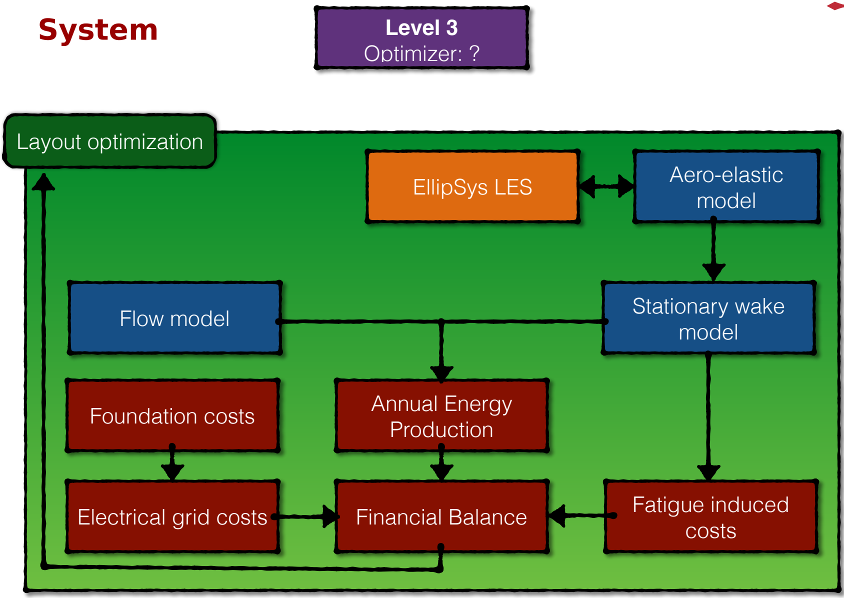
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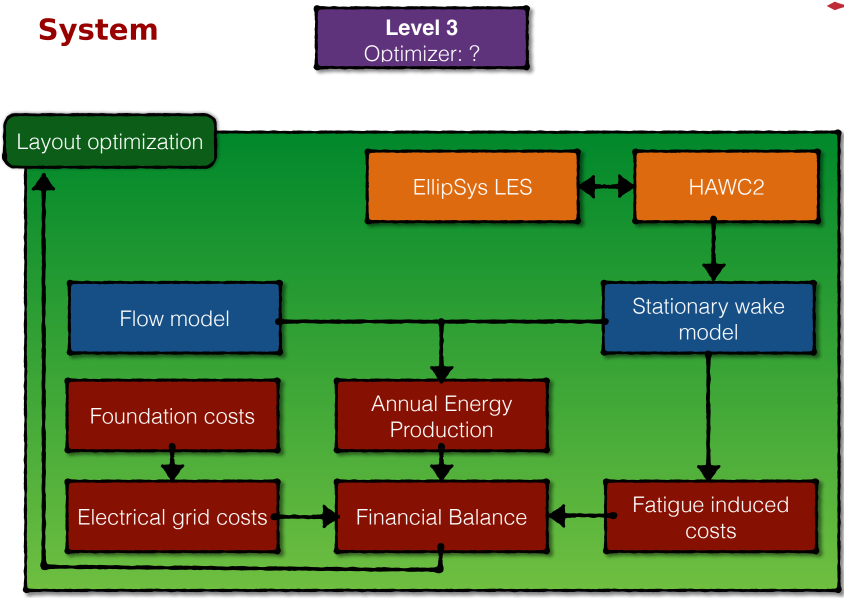

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Optimizer: ?
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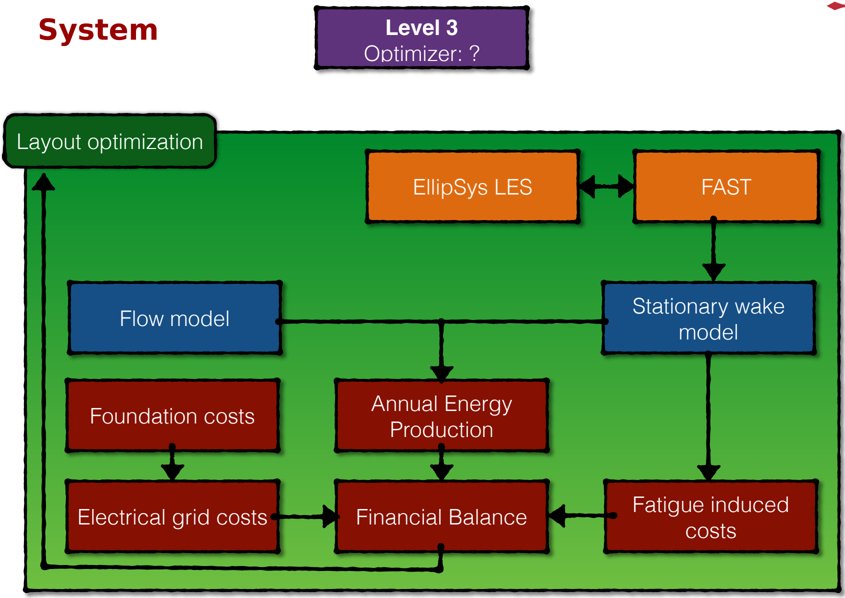

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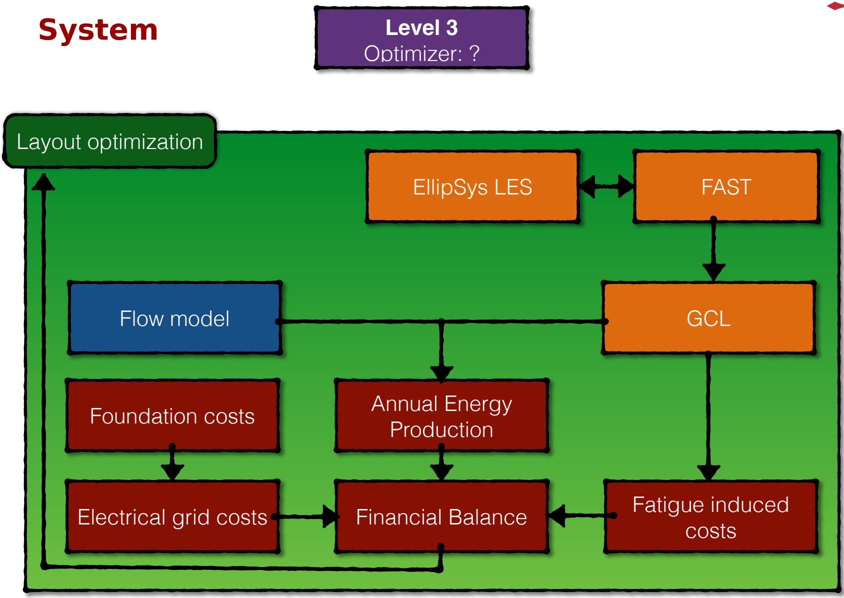
Level 3
Optimizer: ?
Layout optimization
EllipSys LES
FAST
Flow model
GCL
Foundation costs
Annual Energy Production
Electrical grid costs
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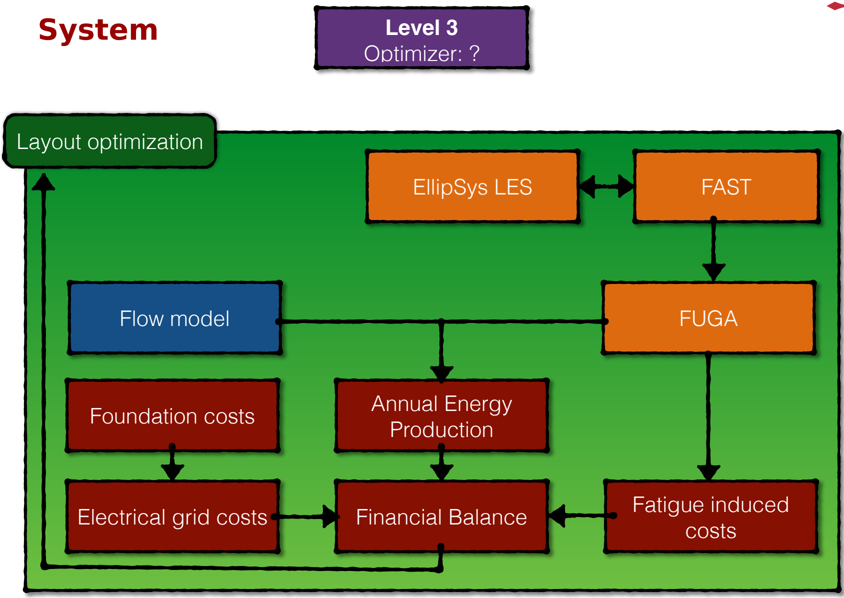
System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EllipSys LES
FAST
Flow model
FUGA
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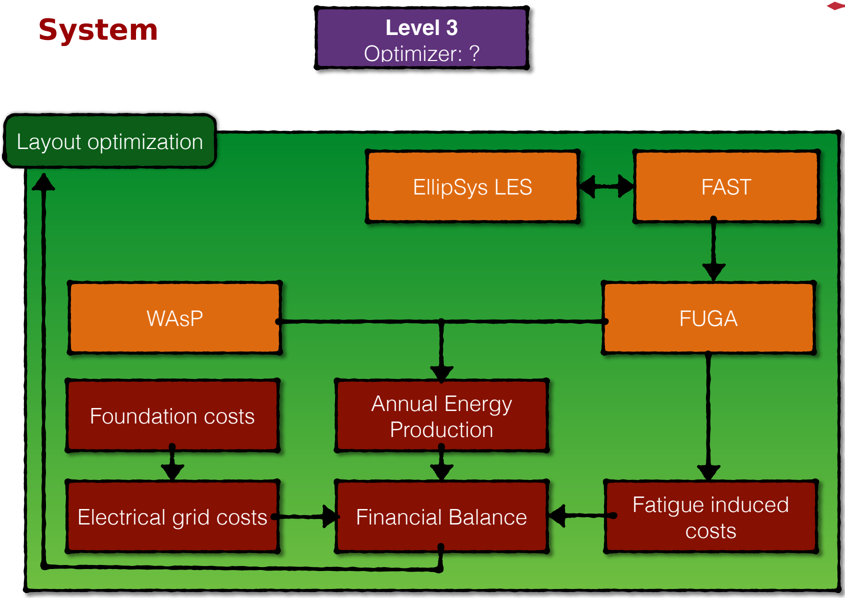

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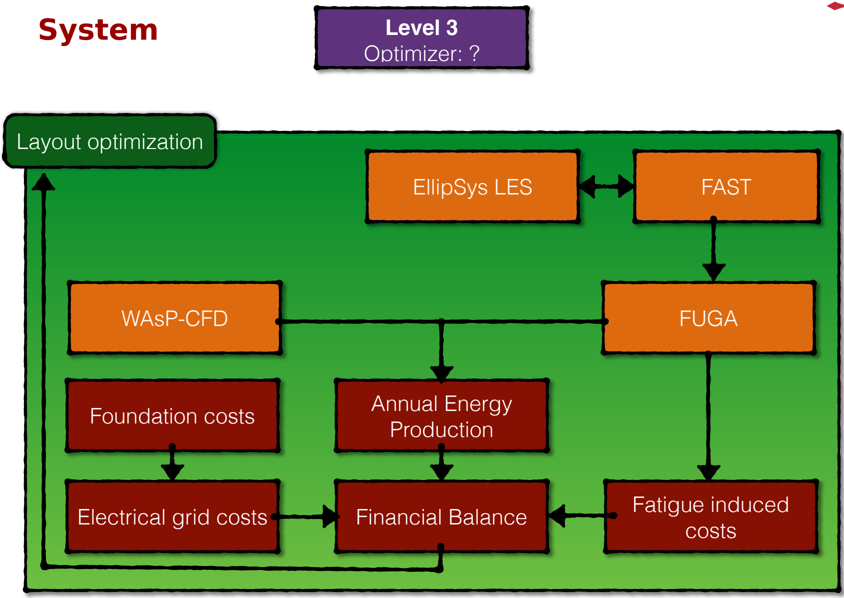

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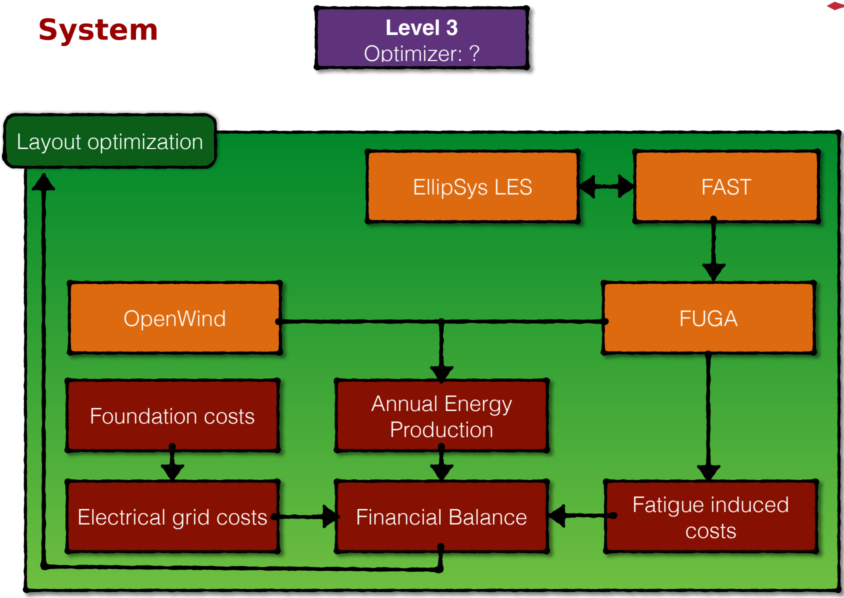
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Layout optimization
EllipSys LES
FAST
OpenWind
FUGA
Foundation costs
Annual Energy Production
Electrical grid costs
Financial Balance
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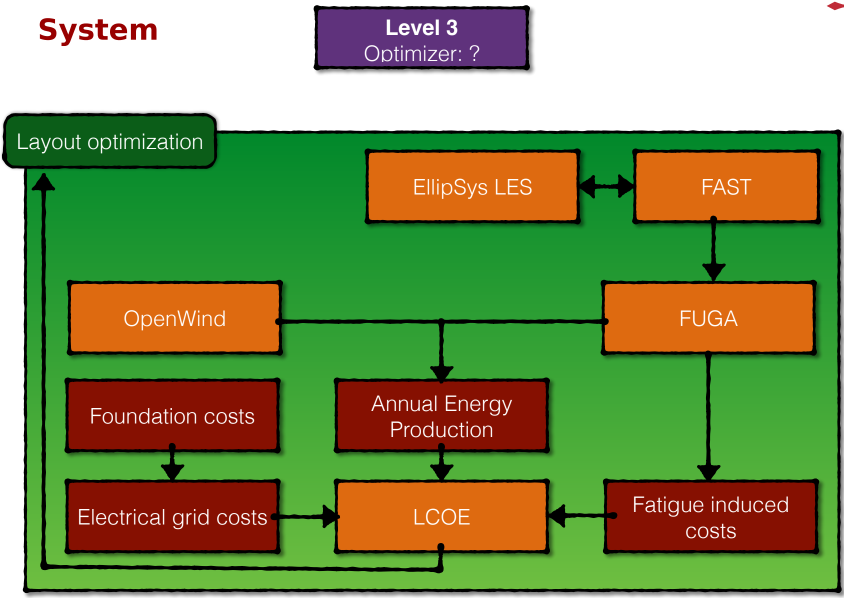

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50+ Optimizers Accessible in TOPFARM

OpenMDAO (6)

- CONMIN
- NEWSUMT
- SLSQP
- COBYLA
- EGO
- Genetic

DAKOTA (24)

- CONMIN_FRGC
- CONMIN_MFD
- DOT_FRGC
- DOT_SQP
- DOT_SLP
- DOT_BFGS
- DOT_MMFD
- NLPQL_SQP
- NLSOL_SQP
- OPTPP_NEWTON
- OPTPP_Q_NEWTON
- OPTPP_FD_NEWTON
- async pattern search
- coliny pattern search
- mesh adapt search
- optpp pds
- coliny cobyla
- coliny solis wets
- coliny ea
- soga
- moga
- ncsu direct
- coliny direct
- EGO

pyOpt (20)

- SNOPT
- NLPQL
- NLPQLP
- FSQP
- SLSQP
- PSQP
- ALGENCAN
- FILTERSD
- SOLVOPT
- SDPEN
- KSOPT
- ...

TOPFARM Roadmap

- **v0.1** January 2015:
  - Level 1
  - wake: GCL
- **v0.2** June 2015:
  - Level 2
  - Fatigue cost model
  - wake: GCL, NOJ, Ainslie, FUGA
  - Definition of DTU Wind new cost model
  - Parallelisation of the optimization on cluster
- **v0.3** January 2016:
  - Connection to WAsP-CFD
  - Level 3
  - wake: EllipSys3D
- **v0.4** June 2016:
  - TOPFARM Cloud Service
  - Load Atlas Cloud Service
  - Wind Farm Flow Model Cloud Service

Future Research Work

- Benchmarking the optimizers
- Definition of reference wind farms
- Multifidelity of wind farm flow models
- Optimization under uncertainty

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The end-user is an expert

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All the modelers consent is required

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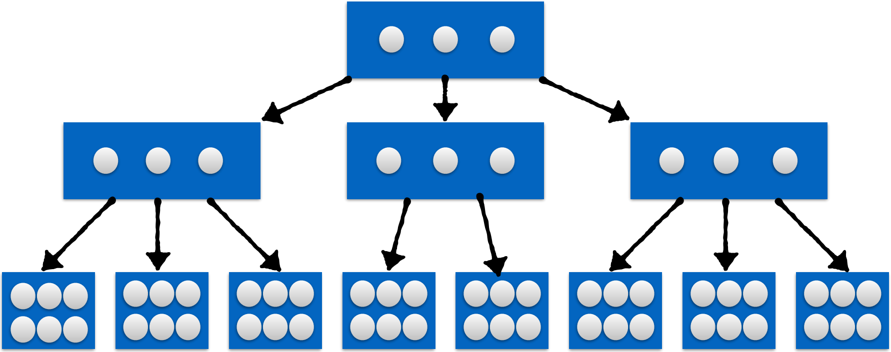
Autocratic hierachies structures make system engineering difficult



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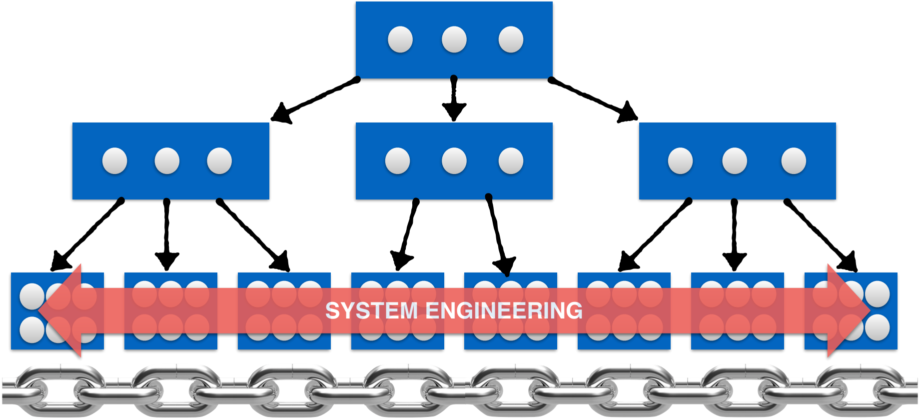
Autocratic hierachies structures make system engineering difficult



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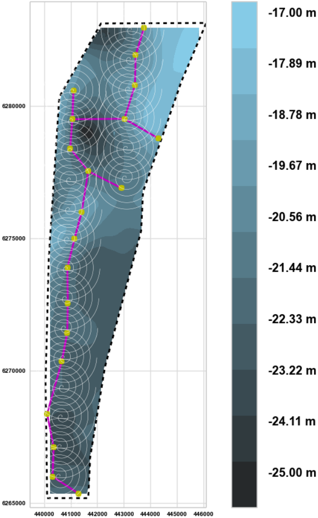
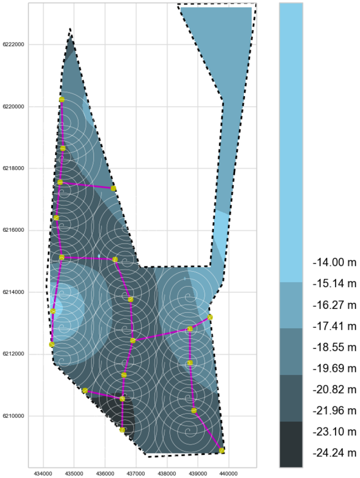
OpenSource is a big plus

People prefer different models





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Dealing with uncertainty

Uncertainty within an optimization can come from different places:

- **Input uncertainty:** The inputs and constraints of the optimization can be uncertain (e.g. wt type, wt description, wind conditions, environemental constraints)
- **User uncertainty:** The user might not know which model to use, or how to use for the models
- **Model uncertainty:** The models add themselves an uncertainty to the results
- **Time pressure:** The optimization should be run fast, with lower fidelity models

Multi-fidelity

"The art of controlling uncertainty by running several similar models of different degrees of precision".

- How to orchestrate when to use which models, and how to project one model on the other one
- Projection: $M_1(x) = M_2(x) + \epsilon(x)$
- $\epsilon(x)$ is a machine-learning algorithm
- The optimization becomes a trade-off between minimizing the objectives and minimizing the variance of ϵ
- Exemple: EGO

Integrating the expert opinion in a belief system

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Sampling and Optimizing at the same time

A wind farm layout optimization requires an expensive AEP calculation. An AEP is in practice the integral of a PDF. It can be seen as a propagation of uncertainty through a wake model. What interest us is to obtain the most accurate AEP at the end of the optimization. During the optimization we can satisfy ourselves with a less accurate AEP. So in that sense we could progressively increase the discretization of the AEP as we converge to a solution. Another way to do it would be to allow slight modifications of a layout as part of the AEP calculation. In other words, we would integrate the AEP taking into considerations the power production of slightly different layouts in different wind speed and wind directions. This would produce of course a higher uncertainty in the AEP, but that might be an acceptable trade-off compared to the time gained.

Meta

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