Infrastructure Optimization in Julia

Carleton Coffrin, et. al.
Los Alamos National Laboratory
Advanced Network Science Initiative

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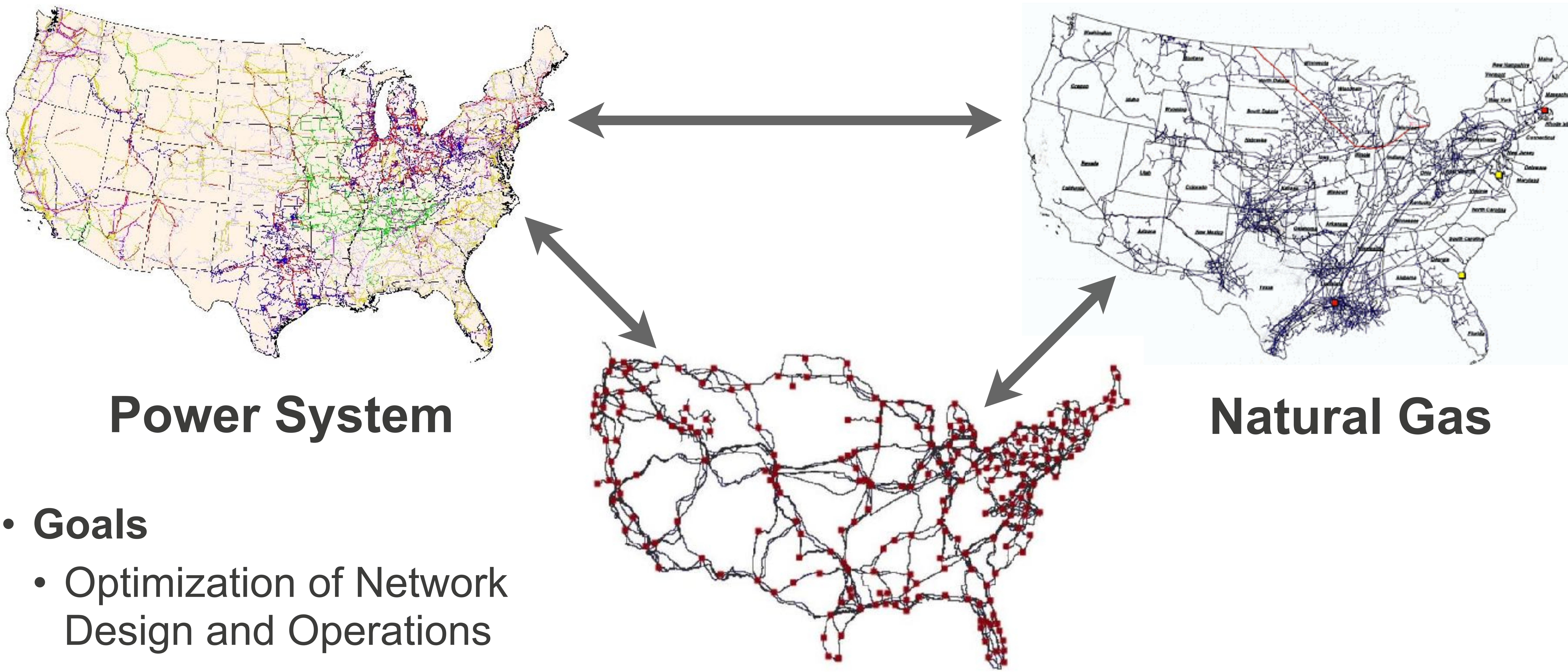
National Infrastructure Networks



Power System

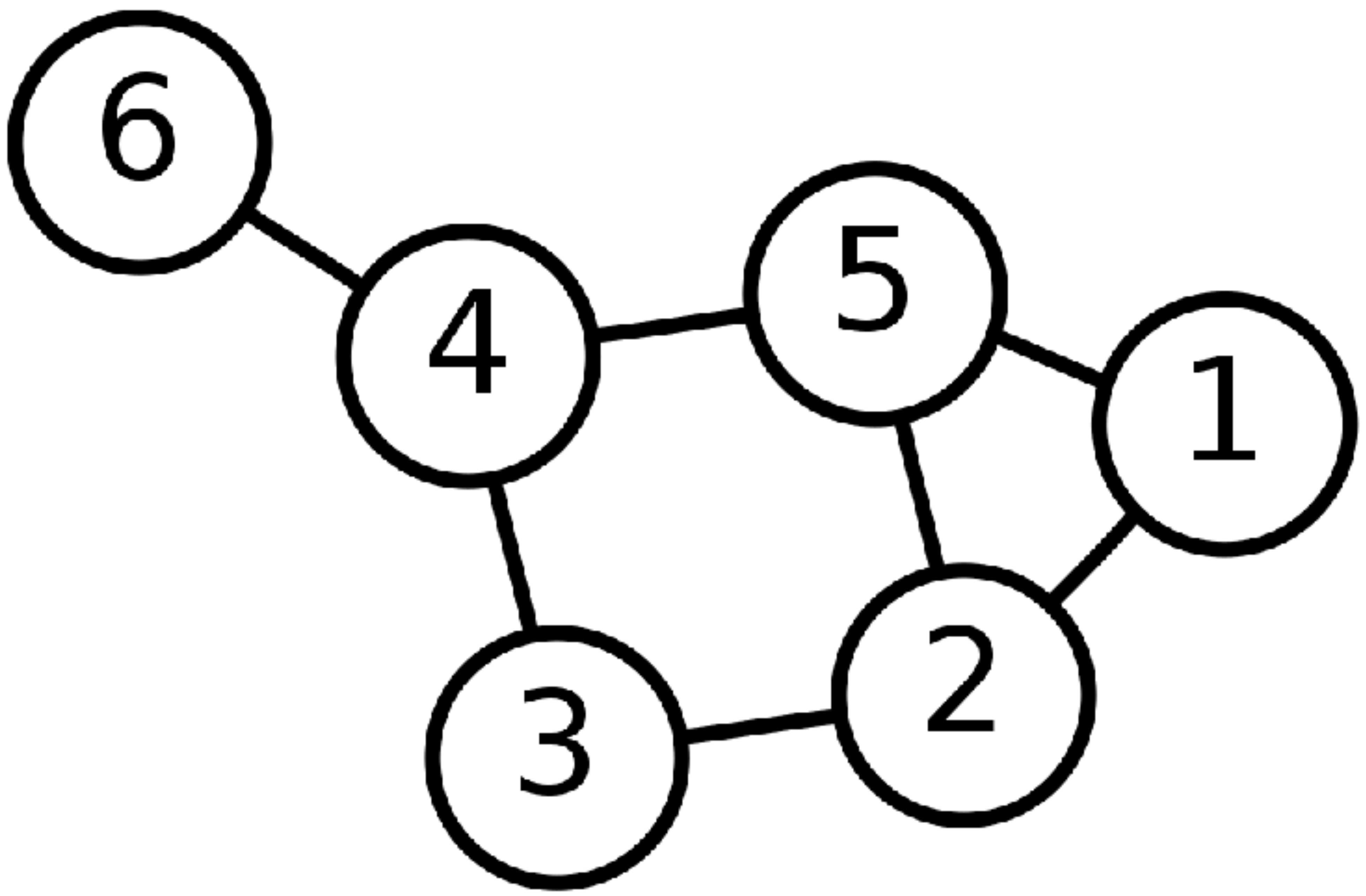
Natural Gas

Communications (Fiber)

- **Goals**
  - Optimization of Network Design and Operations
  - Understand Interdependencies

Common Threads

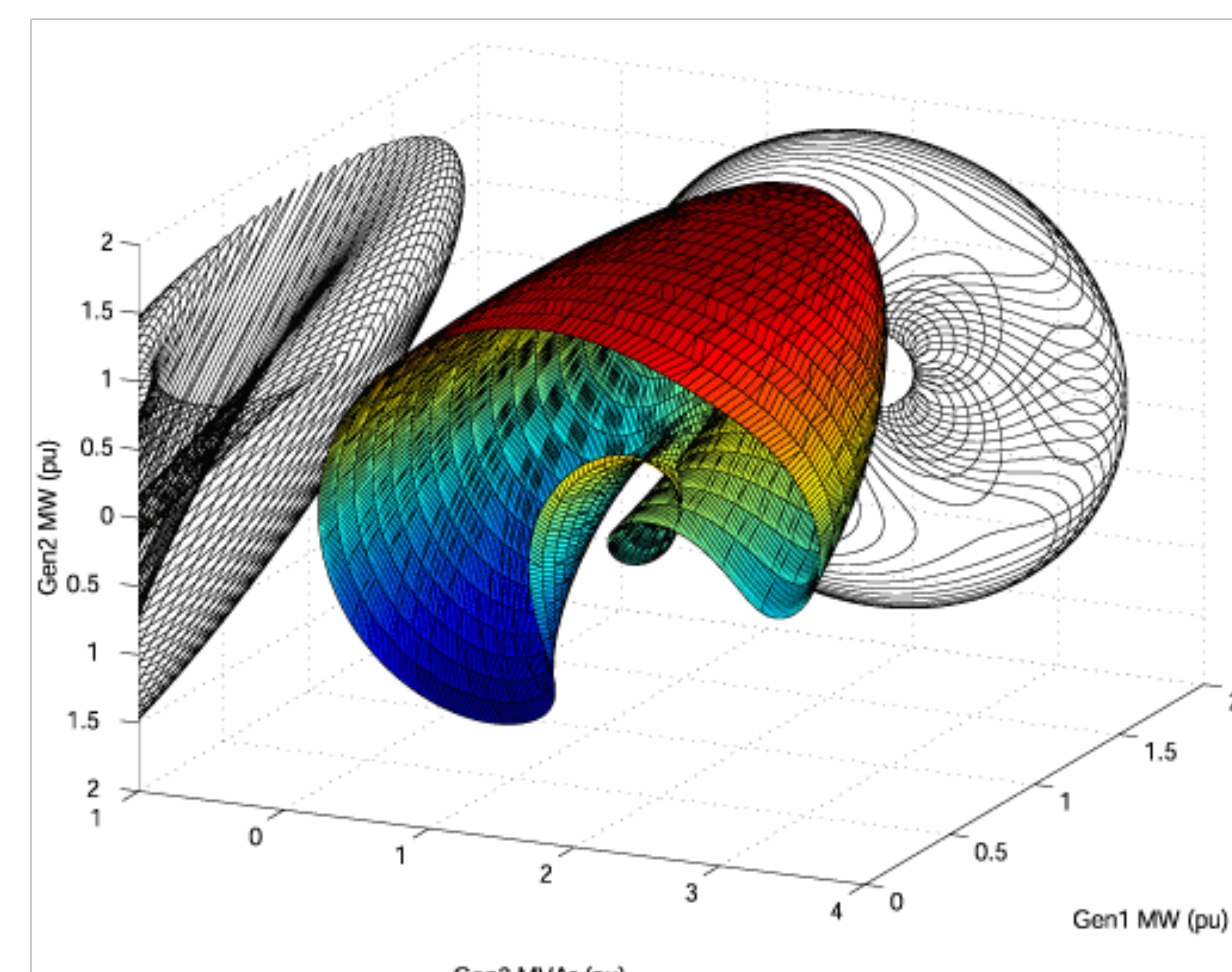
Graph Structure



Physics Equations

$$S_{ij} = \boldsymbol{Y}_{ij}^* V_i V_i^* - \boldsymbol{Y}_{ij}^* V_i V_j^*$$

$$S_i^g - \boldsymbol{S}_i^d = \sum S_{ij}$$

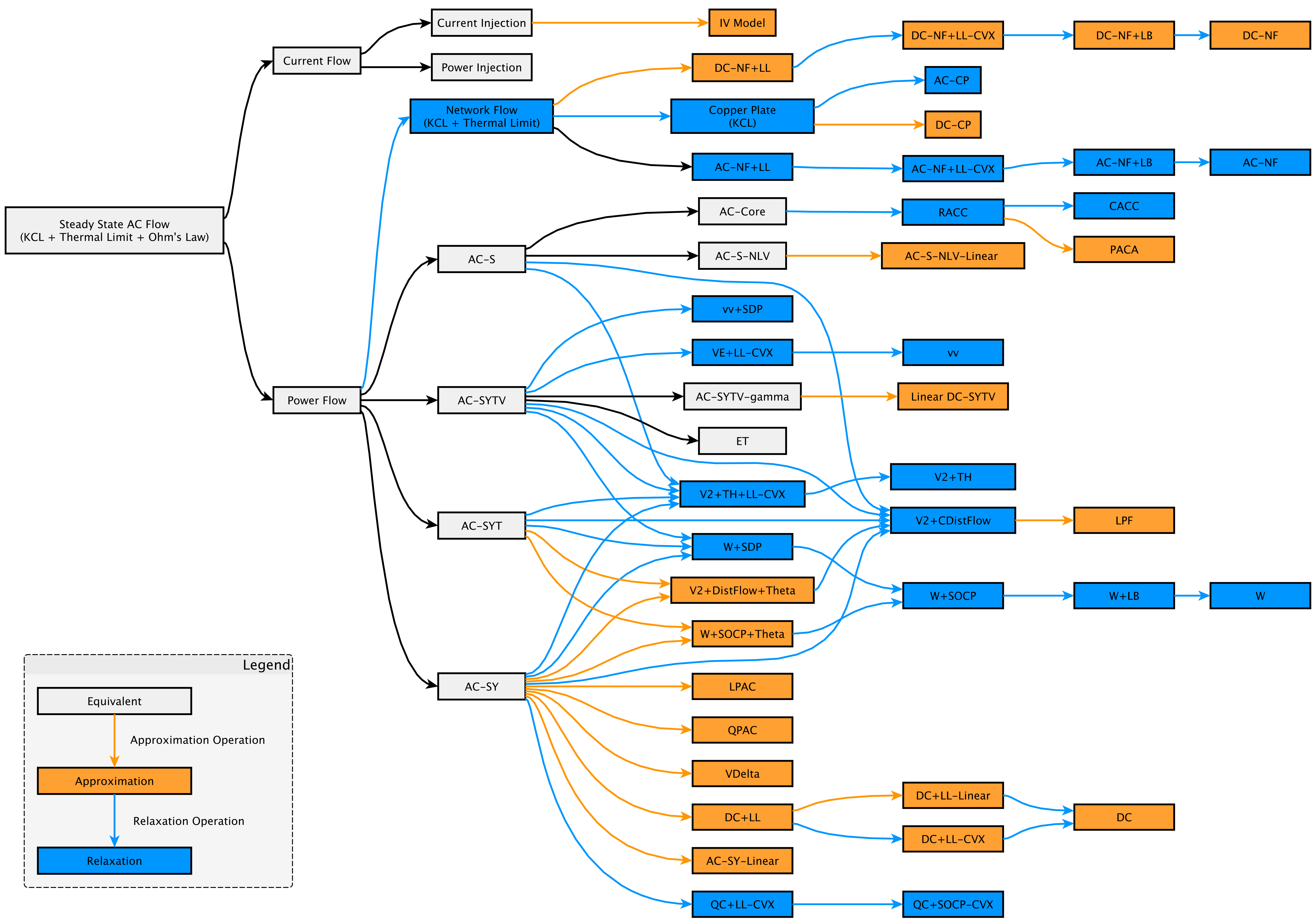


I.A. Hiskens and R.J. Davy, **"Exploring the power flow solution space boundary"**
IEEE Transactions on Power Systems, Vol. 16, No. 3, August 2001, pp. 389-395

Challenges

- **Explosion of physics formulations in recent years**

Taxonomy of Power Flow Formulations (2014)



Also see:
D.K. Molzahn and I.A. Hiskens, **"A Survey of Relaxations and Approximations of the Power Flow Equations,"** to appear in Foundation and Trends in Electric Power Systems, 2018.

Challenges

- **Extremely Wide Range of Optimization Problem Classes**
- **NLP: nonlinear physics in operations**
- **Mixed-Integer: network design decisions**
- **QP / SOC / SDP: convex relaxations**
- **LP: linear approximations**

Three Core Ideas

- **Develop a Infrastructure Network Optimization modeling layer**
  - all formulations share a common mathematical program specification
  - switching formulations (and problem class) is effortless

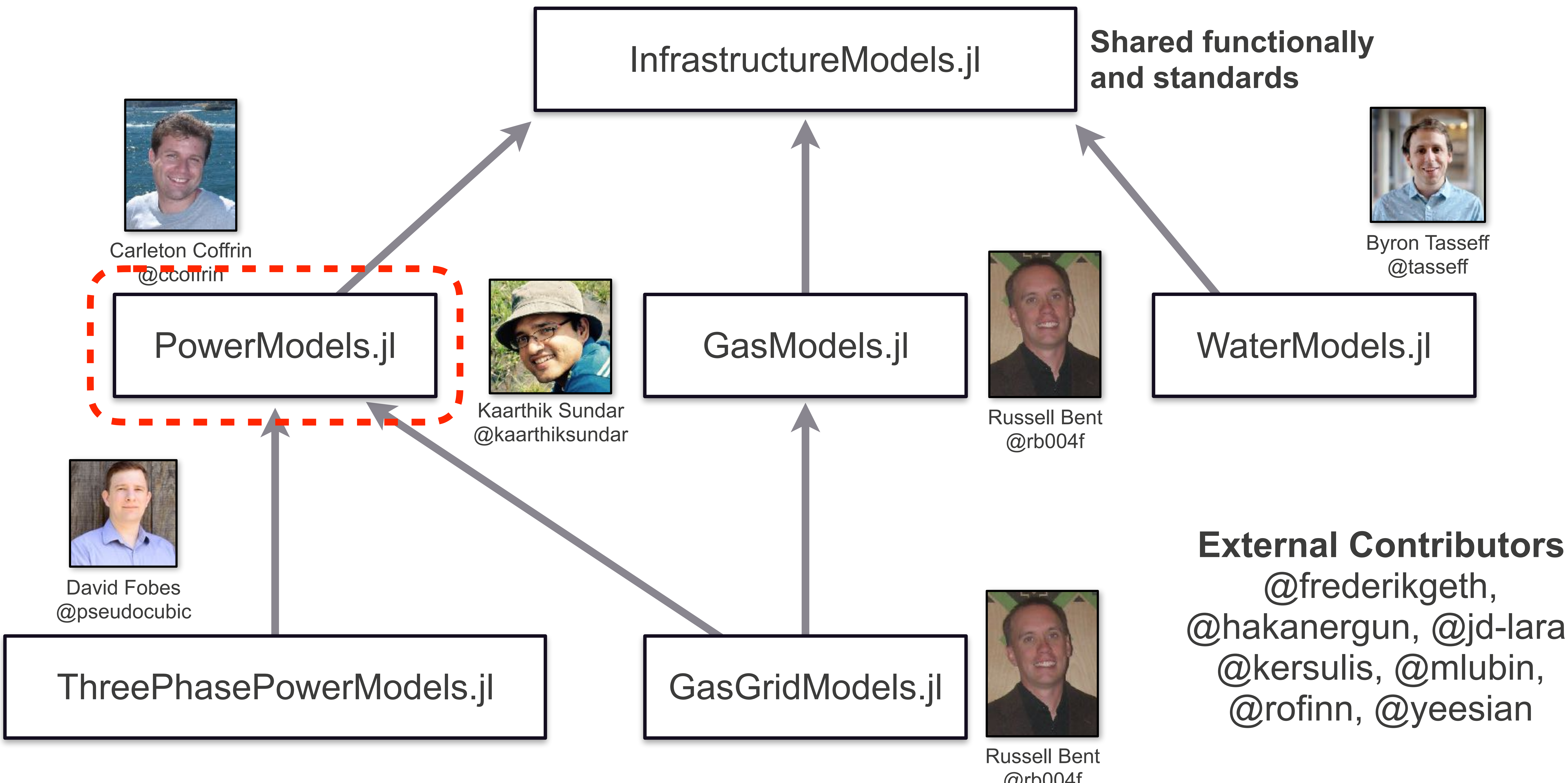
- **Open-source and community driven**
  - formulation authors contribute their implementation
  - most well suited to provide the best version of their formulation idea

- **Common implementation platform**
  - shared problem specification ensure same equations and constraints
  - side-by-side comparisons (e.g. benchmarking) are much more accurate

InfrastructureModels.jl

Open-source Julia packages for Infrastructure Network Optimization

Infrastructure Models Packages



Theme of InfrastructureModels Packages

- Infrastructure-aware JuMP-like modeling layer

- Minimalist Matlab data formats for R&D

- Parsers for Established Data Files
  - e.g. Matpower, PSSE v33, OpenDSS, EPANET

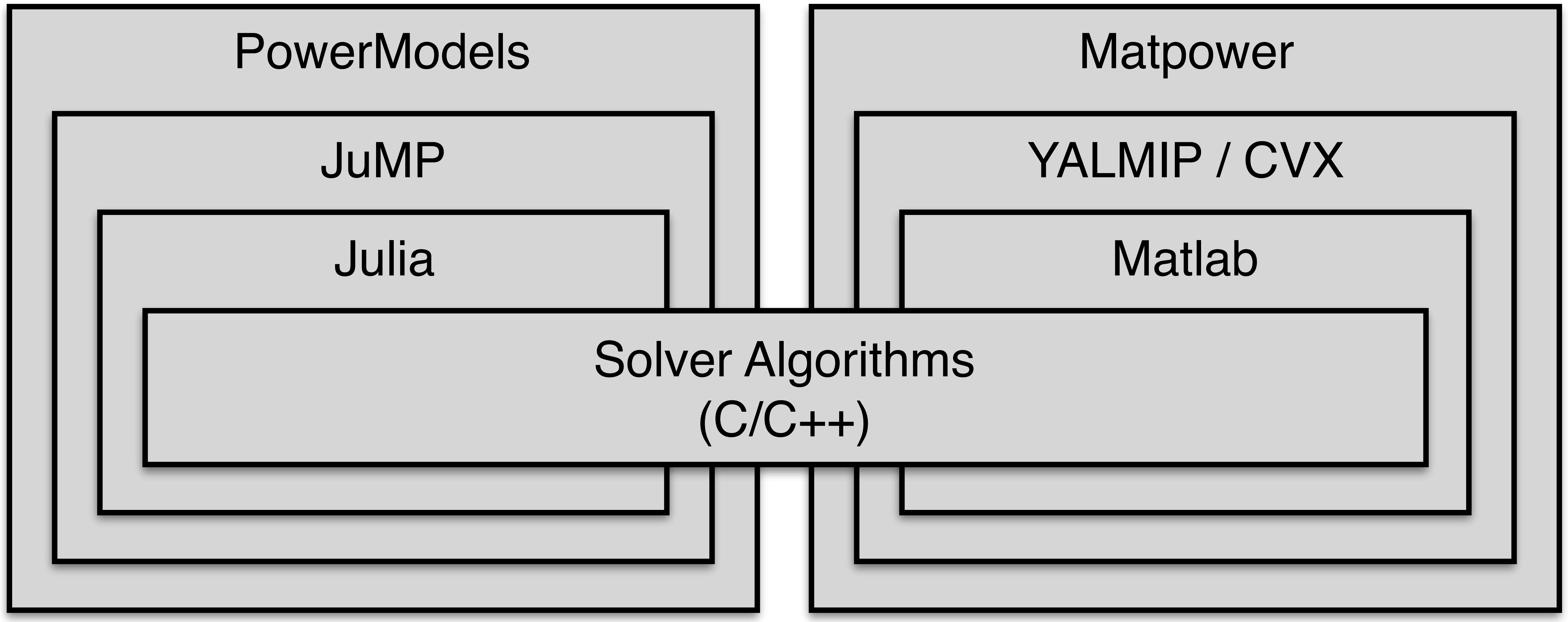
- Cross Infrastructure Data Model Standards
  - Lists of components, organized by component type
  - Universal fields
    - “index” - unique integer id for component
    - “status” - makes components inactive
    - “name” - human readable name

- Goal: Usage of all InfrastructureModels packages “feels” similar

PowerModels.jl

What is PowerModels?

- Data Parsers
  - Matpower (.m)
  - PSSE v33 (.raw)
- Problem Specifications
  - PF, OPF, OTS, TNEP, …
- Formulations
  - AC-Polar, AC-Rect, DC, DC+LL, SDP, SOC, QC, …
- Documentation
  - https://lanl-ansi.github.io/PowerModels.jl/stable/
- Extensions
  - PowerModelsAnnex.jl, ThreePhasePowerModels.jl, PowerModelsReliability.jl, …



Component Model Mapping

Matpower

- Bus+Load+Shunt
- Generator
- Branch (Pi-Model)
  - AC Line
  - Transformer
- Simple DC Line
- Generator Cost
- DC Line Cost

PowerModels

- Bus
- Load
- Shunt
- Generator
- Branch (Pi-Model)
  - AC Line
  - Transformer
- Simple DC Line
- Generator Cost
- DC Line Cost

PSSE (Subset)

- Bus
- ZIP Load
- Fixed Bus Shunt
- Switched Bus Shunt
- Generator
- AC Line (Pi-Model)
- Transformer (T-Model)
  - Two Winding
  - Three Winding
- DC Line
  - Two-Terminal
  - VSC

Want to know more?

https://youtu.be/j7r4onyiNRQ

Example - Reading Data

```
using PowerModels

network_data = PowerModels.parse_file(“pglib_opf_case5_pjm.m”)
```

```
function mpc = pglib_opf_case5_pjm
mpc.version = '2';
mpc.baseMVA = 100.0;

mpc.bus = [
  1  2    0.0    0.00  0.0  0.0  1  1.00000  0.00000  230.0  1  1.10000  0.90000;
  2  1  300.0   98.61  0.0  0.0  1  1.00000  0.00000  230.0  1  1.10000  0.90000;
  3  2  300.0   98.61  0.0  0.0  1  1.00000  0.00000  230.0  1  1.10000  0.90000;
  4  3  400.0  131.47  0.0  0.0  1  1.00000  0.00000  230.0  1  1.10000  0.90000;
  5  2    0.0    0.00  0.0  0.0  1  1.00000  0.00000  230.0  1  1.10000  0.90000;
];

mpc.branch = [
  1  2  0.00281  0.0281  0.00712  400  400  400  0.0  0.0  1  -30.0  30.0;
  1  4  0.00304  0.0304  0.00658  426  426  426  0.0  0.0  1  -30.0  30.0;
  1  5  0.00064  0.0064  0.03126  426  426  426  0.0  0.0  1  -30.0  30.0;
  2  3  0.00108  0.0108  0.01852  426  426  426  0.0  0.0  1  -30.0  30.0;
  3  4  0.00297  0.0297  0.00674  426  426  426  0.0  0.0  1  -30.0  30.0;
  4  5  0.00297  0.0297  0.00674  240  240  240  0.0  0.0  1  -30.0  30.0;
];

...
```

```
Dict{String,Any} with 13 entries:
  "source_type"    => "matpower"
  "name"           => "pglib_opf_case5_pjm"
  "source_version" => v"2.0.0"
  "baseMVA"        => 100.0
  "per_unit"       => true
  "bus"            => Dict{String,Any}(...)
  "branch"         => Dict{String,Any}(...)
  "dcline"         => Dict{String,Any}(...)
  "gen"            => Dict{String,Any}(...)
  "load"           => Dict{String,Any}(...)
  "shunt"          => Dict{String,Any}(...)
  "storage"        => Dict{String,Any}(...)
```

```
network_data["bus"]["1"]["vm"] ... 1.0
network_data["branch"]["3"]["br_x"] ... 0.0064
```

Example - Varying the Problem Formulation

```
using PowerModels; using Ipopt
solver = IpoptSolver()

result = run_ac_opf(network_data, solver)

result = run_dc_opf(network_data, solver)


run_opf(network_data, ACPPowerModel, solver)

run_opf(network_data, DCPPowerModel, solver)

run_opf(network_data, SOCWRPowerModel, solver)
```

Non-Convex Form

Linear Approximation

Convex Relaxation

Shared Problem Specification

Example - Varying the Problem Class

Problem Class

Non-Convex Formulation

Linear Approximation

Convex Relaxation

```
using PowerModels; using Ipopt
solver = IpoptSolver()

# Base Non-Convex Model
run_pf("pglib_opf_case5_pjm.m", ACPPowerModel, solver)
run_opf("pglib_opf_case5_pjm.m", ACPPowerModel, solver)
run_ots("pglib_opf_case5_pjm.m", ACPPowerModel, solver)

# Linear Approximation
run_pf("pglib_opf_case5_pjm.m", DCPPowerModel, solver)
run_opf("pglib_opf_case5_pjm.m", DCPPowerModel, solver)
run_ots("pglib_opf_case5_pjm.m", DCPPowerModel, solver)

# Convex Relaxation
run_pf("pglib_opf_case5_pjm.m", SOCWRPowerModel, solver)
run_opf("pglib_opf_case5_pjm.m", SOCWRPowerModel, solver)
run_ots("pglib_opf_case5_pjm.m", SOCWRPowerModel, solver)
```

PowerModels Mathematical Modeling Layer

```
function post_opf(pm::GenericPowerModel)

    variable_voltage(pm)
    variable_generation(pm)
    variable_branch_flow(pm)

    objective_min_fuel_cost(pm)

    constraint_voltage(pm)

    for i in ids(pm, :ref_buses)
        constraint_theta_ref(pm, i)
    end

    for i in ids(pm, :bus)
        constraint_kcl_shunt(pm, i)
    end

    for i in ids(pm, :branch)
        constraint_ohms_yt_from(pm, i)
        constraint_ohms_yt_to(pm, i)

        constraint_voltage_angle_difference(pm, i)

        constraint_thermal_limit_from(pm, i)
        constraint_thermal_limit_to(pm, i)
    end
end
```

Infrastructure Aware JuMP-like Modeling

Variable Declaration

Objective Function

Component-wise Constraints

Constraints

On to the Jupiter notebook!

https://github.com/lanl-ansi/tutorial-grid-science-2019