Challenges and Opportunities of Open-Source Software: the case of SU2

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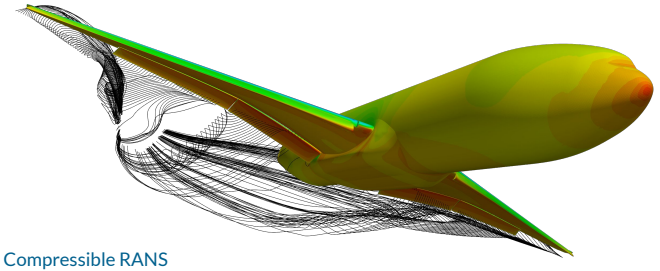
What is SU2?

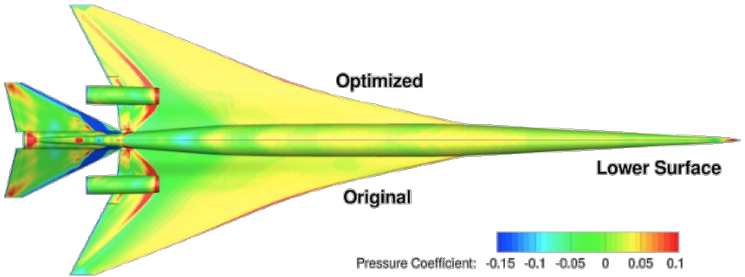
SU2 is an open-source collection of software tools written in C++ and Python, for the analysis of partial differential equations (PDEs) and PDE-constrained optimization problems, using state-of-the-art numerical methods and leading technology for adjoint-based optimization.

How did SU2 start?

- Stanford University, Aerospace Design Laboratory (ADL)
  - Professor Juan J. Alonso
  - Dr. Francisco Palacios
- Computational Fluid Dynamics
  - Reynolds-Averaged Navier Stokes (RANS)
  - Compressible Flows
  - Finite Volume, Unstructured, Multigrid
- Formulated for Design
  - Continuous Adjoint Formulation
  - Aerodynamic Shape Optimization



Compressible RANS



Adjoint-Based Low-Boom Supersonic Aircraft Design

Acknowledgements to the SU2 community for the images

How did SU2 start?

- Stanford University, Aerospace Design Laboratory
  - Professor Juan J. Alonso
  - Dr. Francisco Palacios
- Initial steps
  - 2013 Conference paper
    - Stanford University Unstructured - SU^2
    - 257 citations on google scholar (31.05.19)
  - 2014 Conference paper
    - Validation and Verification
  - 2016 AIAA Journal paper: **SU2**
    - 118 citations on google scholar (31.05.19)

51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition
07 - 10 January 2013, Grapevine (Dallas/Ft. Worth Region), Texas

AIAA 2013-0287

AIAA 2014-0243

AIAA SciTech
13-17 January 2014, National Harbor, Maryland
52nd Aerospace Sciences Meeting

Stanford Univ

AIAA JOURNAL
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SU2: An Open-Source Suite for Multiphysics Simulation and Design

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This paper presents the main objectives and a description of the SU2 suite, including the novel software architecture and open-source software engineering strategy. SU2 is a computational analysis and design package that has been developed to solve multiphysics analysis and optimization tasks using unstructured mesh topologies. Its unique architecture is well suited for extensibility to treat partial-differential-equation-based problems not initially envisioned. The common framework adopted enables the rapid implementation of new physics packages that can be tightly coupled to form a powerful ensemble of analysis tools to address complex problems facing many engineering communities. The framework is demonstrated on a number, solving both the flow and adjoint systems of equations to provide a high-fidelity predictive capability and sensitivity information that can be used for optimal shape design using a gradient-based framework, goal-oriented adaptive mesh refinement, or uncertainty quantification.

Nomenclature

$\boldsymbol{A}^c$	=	Jacobian of the convective flux with respect to $\boldsymbol{U}$
$\boldsymbol{A}^{vk}$	=	Jacobian of the viscous fluxes with respect to $\boldsymbol{U}$
$\boldsymbol{B}$	=	column vector or matrix B_i unless capitalized symbol clearly defined otherwise
$\boldsymbol{B}$	=	(B_x, B_y) in two dimensions, or (B_x, B_y, B_z) in three dimensions
B^T	=	transpose operation on column vector or matrix B
$\boldsymbol{b}$	=	spatial vector $\boldsymbol{b} \in \mathbb{R}^n$, where n is the dimension of the physical Cartesian space (in general, two or three)
C_D	=	coefficient of drag
C_L	=	coefficient of lift
C_{M_z}	=	pitching-moment coefficient
C_p	=	coefficient of pressure
c	=	airfoil chord length
c_p	=	specific heat at constant pressure
$\tilde{\boldsymbol{D}}^{vk}$	=	Jacobian of the viscous fluxes with respect to ∇U
d_s	=	nearest wall distance
$\boldsymbol{d}$	=	force projection vector
E	=	total energy per unit mass
$\tilde{F}^c_{ij}$	=	numerical convective flux between nodes i and j
$\tilde{F}^v_{ij}$	=	numerical viscous fluxes between nodes i and j
$\boldsymbol{F}^c$	=	convective flux
$\boldsymbol{F}^{vk}$	=	viscous fluxes
f	=	force vector on the surface
$\tilde{I}$	=	identity matrix
J	=	cost function defined as an integral over S
j	=	scalar function defined at each point on S
k	=	turbulent kinetic energy
$\mathcal{N}(i)$	=	set of all neighboring nodes of node i
$\boldsymbol{n}$	=	unit normal vector
P	=	shear–stress transport turbulent kinetic energy production term
Pr_d	=	dynamic Prandtl number
Pr_t	=	turbulent Prandtl number
p	=	static pressure
Q	=	vector of source terms
q_ρ	=	generic density source term
$q_{\rho E}$	=	generic density source term
$\boldsymbol{q}_{\rho \boldsymbol{v}}$	=	generic momentum source term
R	=	gas constant
$\mathcal{R}(U)$	=	system of governing flow equations
Re	=	Reynolds number
$\mathcal{R}_i$	=	system of governing equation residual at node i
S	=	solid wall flow domain boundary
$\tilde{S}$	=	Spalart–Allmaras turbulence production term
T	=	temperature
t	=	time variable
U	=	vector of conservative variables
W	=	vector of characteristic variables
W_+	=	vector of positive characteristic variables
W_∞	=	far-field characteristic variables
Γ	=	flow domain boundary
Γ_∞	=	far-field domain boundary
γ	=	ratio of specific heats, equal to 1.4 for air
ΔS_{ij}	=	interface area between nodes i and j
$\delta(\cdot)$	=	first variation of a quantity
$\partial_{\boldsymbol{n}}(\cdot)$	=	normal gradient operator at a surface point, $\boldsymbol{n}_S \cdot \nabla(\cdot)$
μ_{dyn}	=	laminar dynamic viscosity
μ_{tur}	=	turbulent eddy viscosity
μ^{vt}	=	total viscosity as a sum of dynamic and turbulent components, $\mu_{dyn} + \mu_{tur}$
μ^{ct}	=	effective thermal conductivity; $(\mu_{dyn}/Pr_d)+(\mu_{tur}/Pr_t)$
$\boldsymbol{v}$	=	flow velocity vector
ρ	=	fluid density
τ	=	pseudotime

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Open-source
bulent Flows

Trent W. Lukaczyk†
dan Tracey‡ Anil Variyar‡

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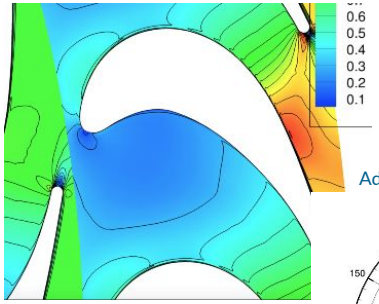
ities, AIAA Student Members.

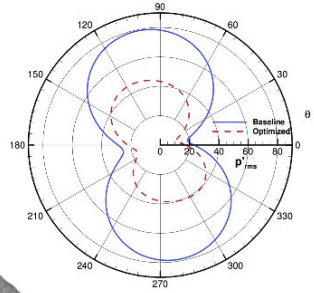
SU2 expands...

- Released on GitHub under LGPL 2.1: **github.com/su2code/SU2**
- Chair of Propulsion and Power, TU Delft, Netherlands
  - Turbomachinery, Non-Ideal Compressible Fluid Dynamics (NICFD)
- Chair of Scientific Computing, TU Kaiserslautern, Germany
  - Discrete Adjoint based on Algorithmic Differentiation, Aeroacoustics
- CREA Lab, Politecnico di Milano, Italy
  - NICFD, Rotorcraft Icing
- Load Control and Aeroelastics, Imperial College London, UK
  - Fluid-Structure Interaction and Aeroelasticity

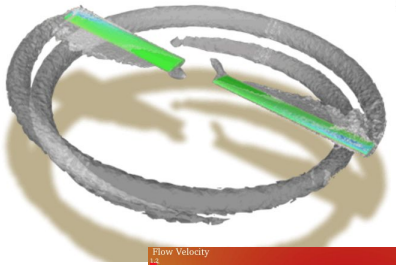
Adjoint-Based Turbomachinery Design

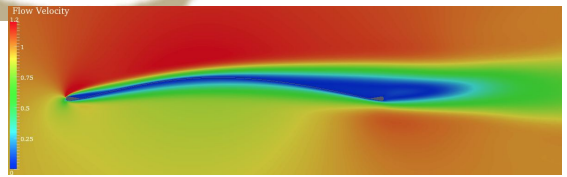


Adjoint-Based Aeroacoustics Design



Rotating Frame





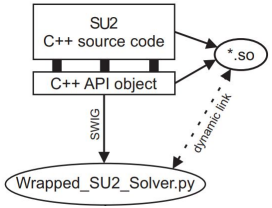
Membrane-Wing Fluid-Structure Interaction

Acknowledgements to the SU2 community for the images

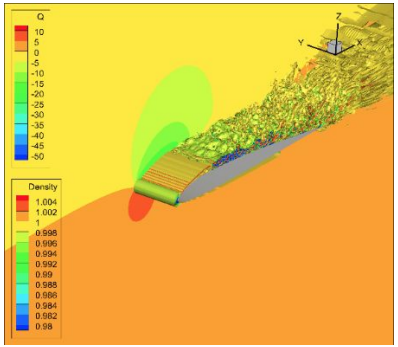
SU2 expands...

- MTFC Group, University of Liege, Belgium
  - Python wrapping using SWIG
- Prof. van der Weide Group, University of Twente, Netherlands
  - High-Order Discontinuous Galerkin
- Lab. of New Concepts in Aeronautics, ITA, Brazil
  - Detached-Delayed Eddy Simulation (DDES)
- … and many others …

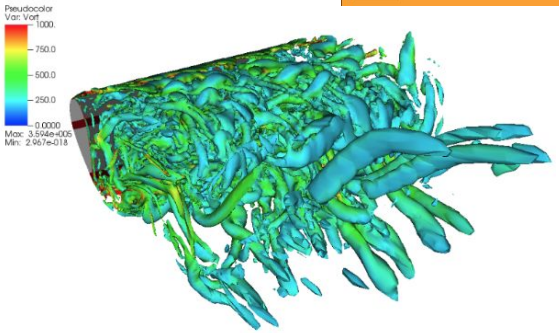
Python-wrapper Implementation



High-Order Discontinuous Galerkin



Detached Delayed Eddy Simulation



Acknowledgements to the SU2 community for the images

SU2 expands...

➔ Presenters at our 4th developers meeting last month also from...

- Robert Bosch LLC, CA, USA
- National Institute of Aerospace, VA, USA
- Universidad Carlos III Madrid, Spain
- Universität Würzburg, Germany
- Weierstraß Institut Berlin, Germany
- ECN part of TNO, Netherlands
- Robert Bosch GmbH, Germany
- University of Strathclyde, UK

From a 1-institution CFD code to...

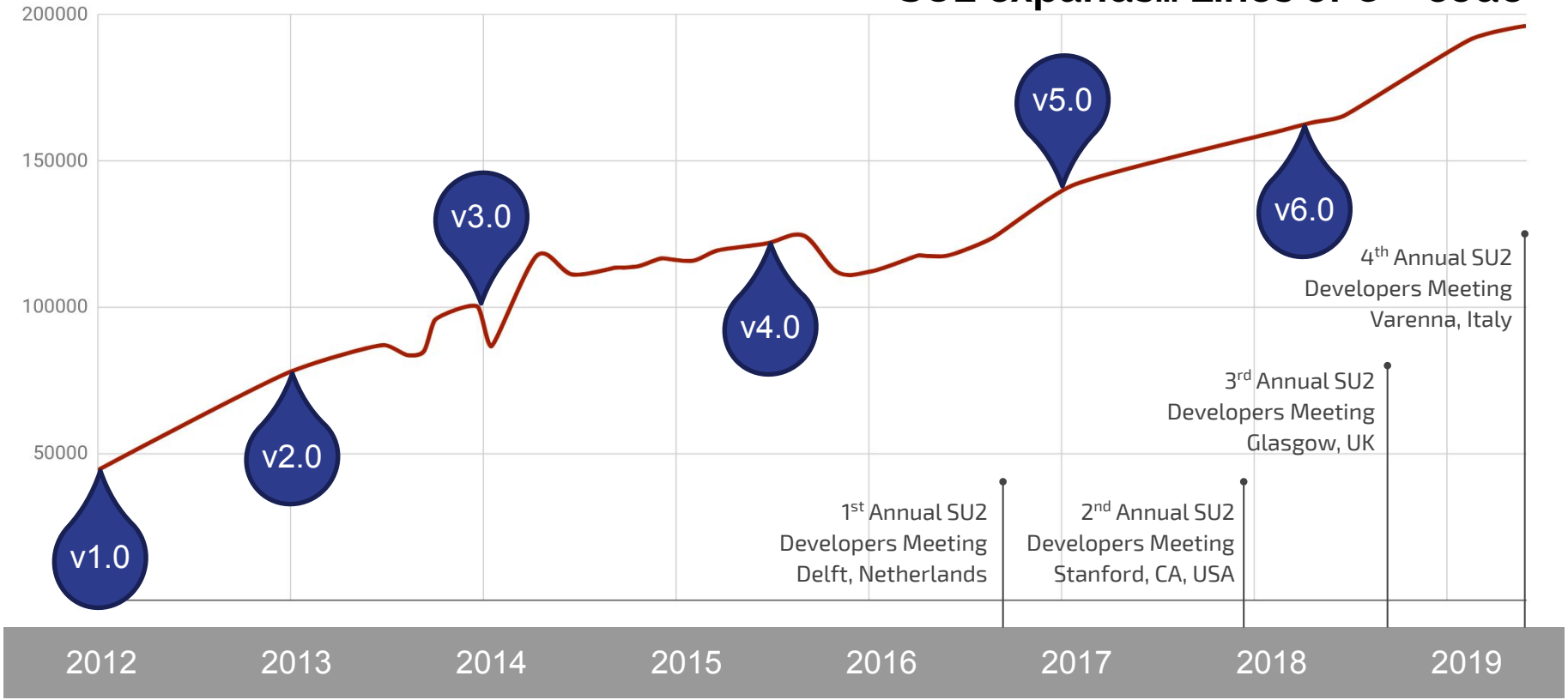
~10000+ repo visits/month*

~1000+ repo clones/month*

~400+ repo forks

*From the github repo, between 18/05 and 31/05: 5,445 views, 612 clones

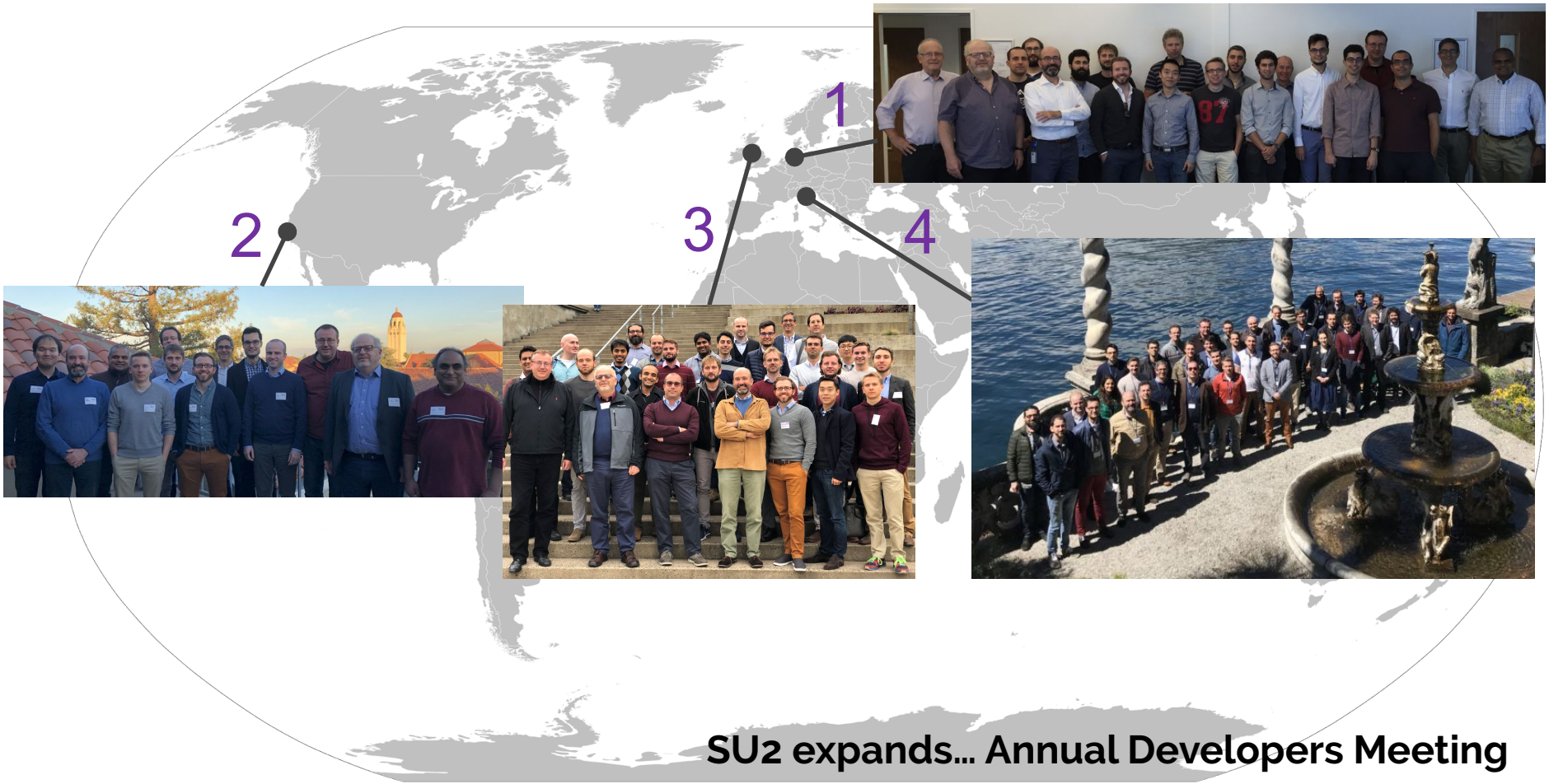
SU2 expands... Lines of C++ code



TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Scientific Computing

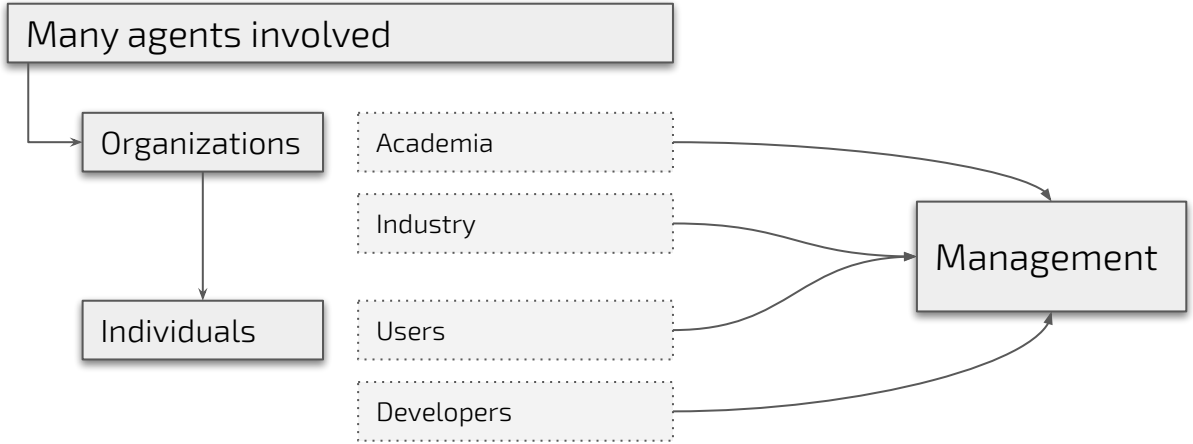
SU2 foundation

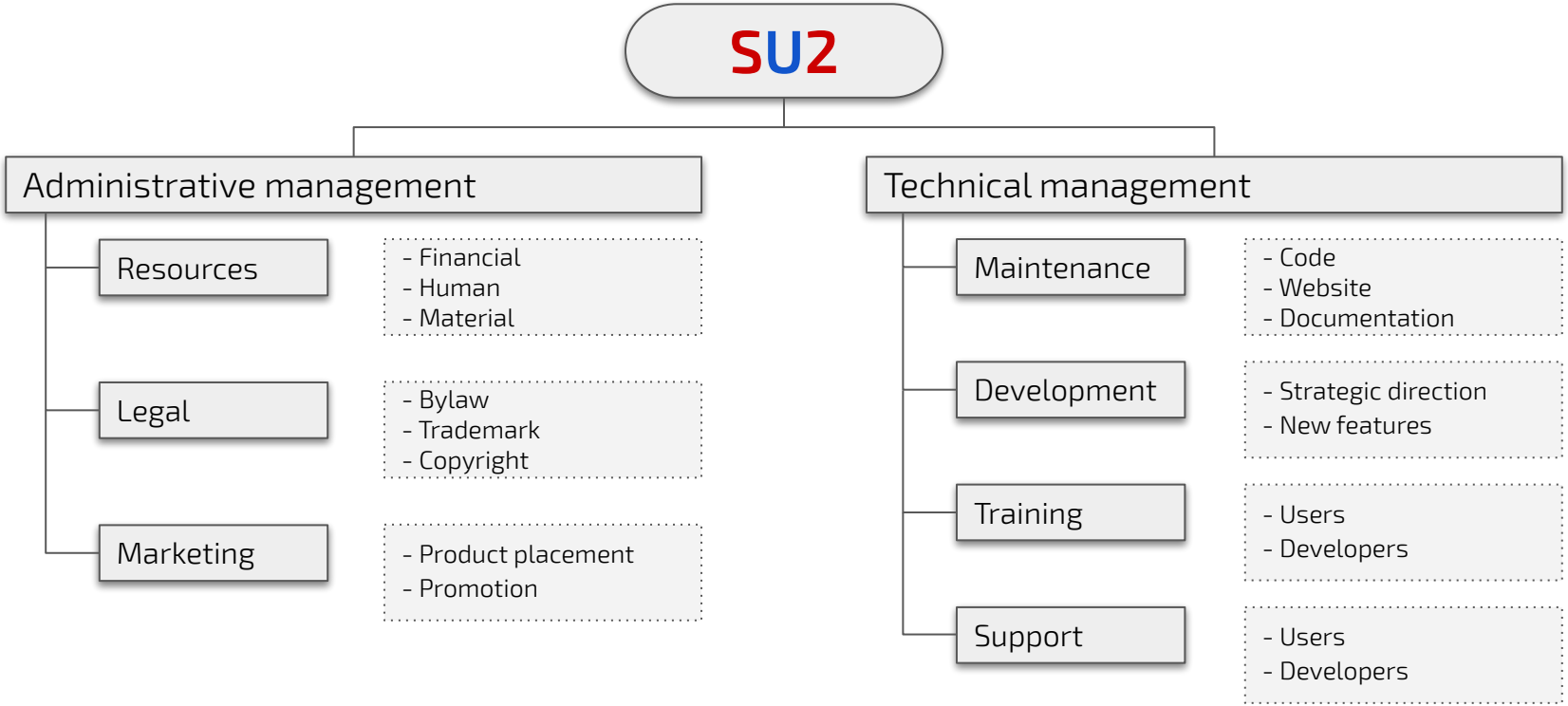


SU2 expands... Annual Developers Meeting

SU2

… has a global impact




SU2
Administrative management
Resources
- Financial
- Human
- Material
Legal
- Bylaw
- Trademark
- Copyright
Marketing
- Product placement
- Promotion
Technical management
Maintenance
- Code
- Website
- Documentation
Development
- Strategic direction
- New features
Training
- Users
- Developers
Support
- Users
- Developers

INDUSTRY

- *"I want to obtain a fast solution"*
- *"I want a product that is* ***easy to integrate*** *into my processes"*
- ***"I want a reliable product"***

ACADEMIA

- *"I want a product with the latest methods"*
- *"I want to leverage on the community's expertise"*
- ***" I want to publish"***

USERS

- *"I want a product that is easy to use"*
- *"I want a product that is well* ***documented****"*
- ***"I want a free product that fits my needs"***

DEVELOPERS

- *"I want a code that is easy to extend"*
- *"I want to get* ***support*** *from other developers"*
- ***"I want to develop my career"***

Challenges

➔ Most of the development of SU2 has been (so far) carried out at Universities

- Developers are in many cases PhD students
- Pressure to implement novel methods/features and generate results ⟶ Code quality/sustainability not priority
- Developers are not necessarily experienced software engineers:
  - Aeronautical engineers
  - Mechanical engineers
  - Civil engineers
  - Mathematicians
  - ...

Challenges

➔ Very little motivation or incentive to do non-glamorous and **non-publishable** work:

- **Documentation** ⟶ Generating developer docs and tutorials takes up time
- **Code usability** ⟶ State-of-the-art features need to be usable by a broad audience
- **Code architecture** ⟶ Integration of a growing number of features requires planning
- **Code maintenance** ⟶ Important features such as input, output, parallel support require constant improvements
- **Code reviews** ⟶ Require expertise and insight on the code

Challenges

➔ Career challenges for developers:

- Little (if any) public research funding available for the maintenance of open-source tools
- Experienced developer finalizing his/her PhD...
  - **Industrial career path:** companies value the developer's insight on the code, but might not be keen to share new developments/improvements/features done in-house to the codebase
  - **Academic career path:** highly competitive academic positions depend very much on publication rates
- Continuing developers are in most cases investing big parts of their personal time to maintaining and supporting SU2

Challenges

➔ Lack of centralized infrastructure:

- **Strategic direction** ⟶ What are the code priorities? How are resources allocated? Who decides if some feature cannot be integrated?
- **Point of contact** ⟶ No clear point of contact for new developers
- **Support** ⟶ It is complicated to invest time and provide support to users

SU2 Foundation

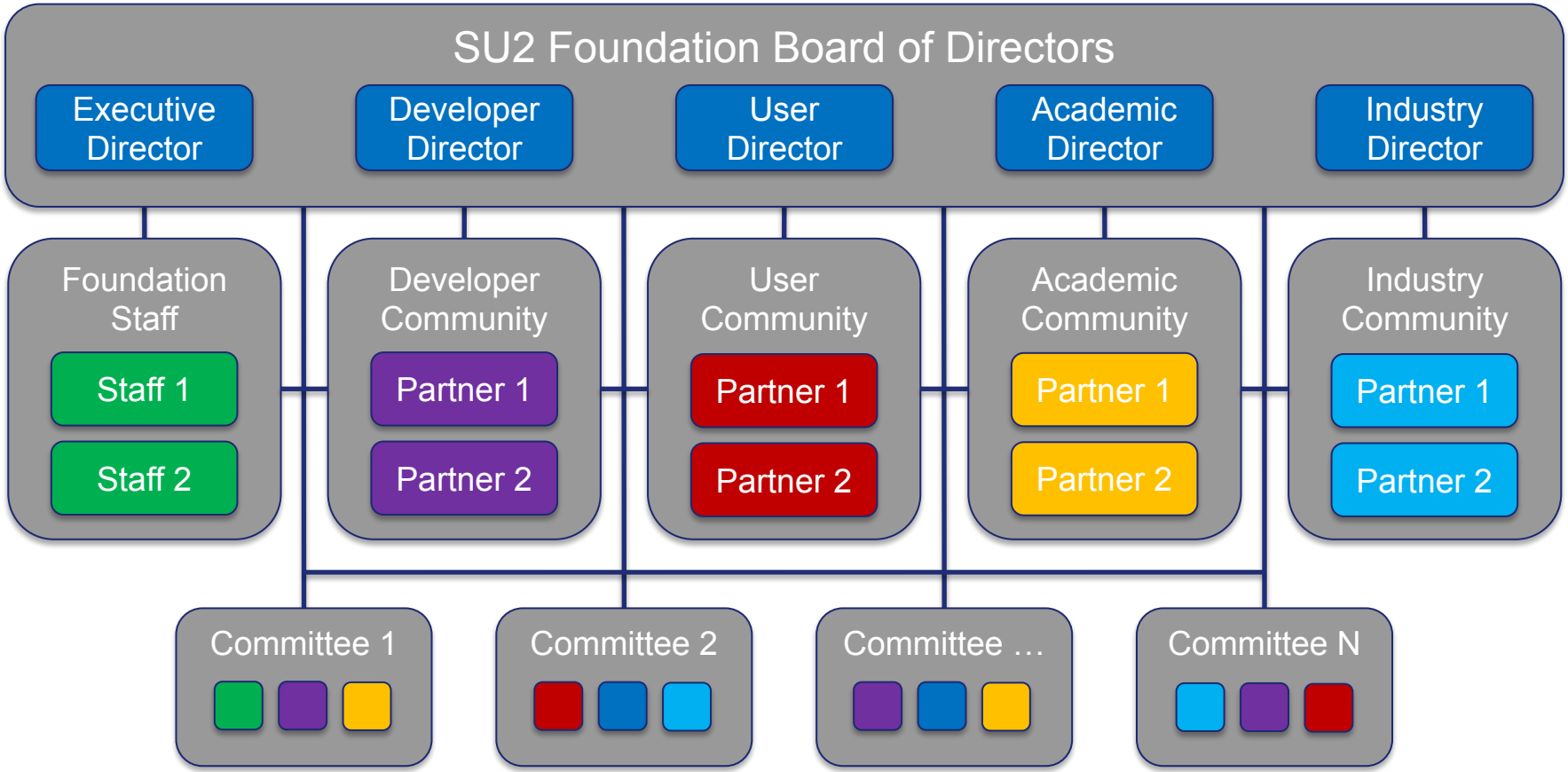
A mission-driven, nonprofit organization:

(a) promote global software development and education to increase the pace of innovation in the engineering sciences for the public benefit of all society;

(b) provide a neutral forum for community collaboration by offering efficient infrastructure and technical governance;

SU2 Foundation

- On May 2, the SU2 Foundation was officially incorporated and recorded in the state of Delaware
- Proposed as a non-profit entity in California pursuing 501(c)(3) status
- The governance of the Foundation will be carried out by the Board of Directors, 5 at the moment
- The directors will empower the community to keep contributing to the open-source project and to decide on its future through working groups and committees
- The Foundation will undertake the activities that deems appropriate to further the purposes and achieve the goals set in the mission


SU2 Foundation Board of Directors
Executive Director
Developer Director
User Director
Academic Director
Industry Director
Foundation Staff
Staff 1
Staff 2
Developer Community
Partner 1
Partner 2
User Community
Partner 1
Partner 2
Academic Community
Partner 1
Partner 2
Industry Community
Partner 1
Partner 2
Committee 1
Committee 2
Committee …
Committee N

SU2 Foundation

➔ Some proposals to recognize the volunteers for non-publishable work:

- Certificates
- Awards
- Gamification (point system/top developers list)

SU2 Foundation

➔ Some proposals to increase interaction with developers:

- Office hours (Rocket Chat)
- Videos/live feed on meetings
- Social platform

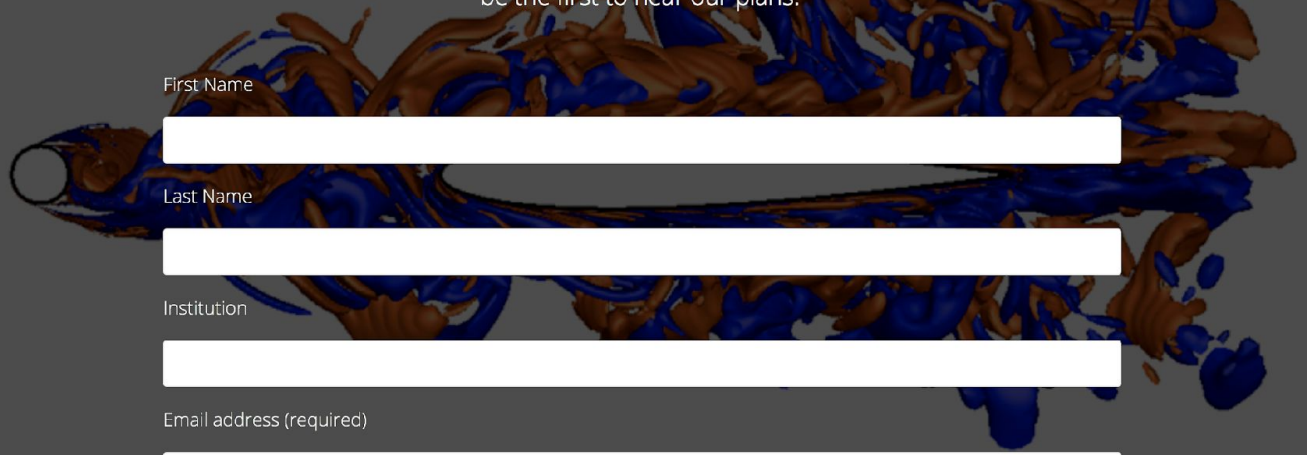
1225 4th St. #333, San Francisco, CA 94158 info@su2foundation.org

SU2 foundation

PROJECTS ACTIVITIES ABOUT US

Promoting open innovation in engineering software

At the intersection of education, research, and open software development, we're driving innovation in the engineering sciences for the benefit of all society from our headquarters in Silicon Valley. Sign up today to be the first to hear our plans.



First Name

Last Name

Institution

Email address (required)

I consider myself as part of the following communities

- [ ] User
- [ ] Developer
- [ ] Industry
- [ ] Academia

su2foundation.org

Questions?

Feedback welcome!

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