Nautilus21

A generic, integrated, and scalable 3D ocean simulator for scientific exploration and management of Norway's coastal waters and fjords

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Outline

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Abstract

In this paper we present Nautilus21, an interdisciplinary collaborative research project involving staff at the Aalesund University College (AAUC) and regional partners from both the public and private sectors in the north west region of Norway. The project is currently under evaluation by the Research Council of Norway as a strategic university college project ("strategisk høgskoleprosjekt" (SHP)), with a total budget of about 24 MNOK. The primary objective of Nautilus21 is to develop a generic, integrated, and scalable 3D simulator for modelling, simulation, and visualisation of Norway's coastal waters that can be used for research, education, innovation, industrial development, and public management. To achieve this objective, we propose as a first step to use two real-world case studies of the two Norwegian fjords Borgundfjorden and Storfjorden as a driver for all development stages of a regional prototype of our simulator. The case studies aim to link oceanographic data and human activity to relevant

Abstract (cont.)

biological research questions with respect to dispersals of particles, or agents, in coastal waters and resulting effects on marine ecosystems. Factors such as climate change, ship traffic, industry, urban waste, pollutants, fish farms, and infectious fish diseases and their interactions with the food web will be examined. There is a fine balance between creating sustainable value and negative influence on the ecosystem. Tying the design and development stages of the simulator to practical problems from the very start will serve as a guidance for the project, with each stage resulting in both theoretical and applied research contributions. Importantly, upon completion, the simulator shall be generic in nature and easy to extend to other research case studies in the marine environment, including not only coastal waters and fjords but also the ocean space.

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Development goals for the marine industry

- *Regional* goal: Continuing development of marine industry
  - keep Møre & Romsdal #1 seafood county in Norway
  - secure employment and population growth
- *National*[1] goal: Norway shall become #1 seafood nation in the world!
  - how? — by new and innovative use of coastal waters and fjords
- Regulative[2] and scientific[3] *global* goals: sustainable management and exploitation of marine ecosystems

[1] St. meld. 22 (2012-13)
[2] e.g., EU Water Framework Directive (Vanndirektivet)
[3] e.g., Horizon 2020's Blue Growth

Our proposed contribution towards achieving goals

Nautilus21

a generic, integrated, and scalable 3D ocean simulator for scientific exploration and management of Norway's coastal waters and fjords

- Modelling, simulation, and visualisation of coast and fjords
- Two case studies: Borgundfjorden and Storfjorden
- Aim: *link oceanographic data and human activity to biological research questions*
  - dispersal of particles and effect on ecosystems
  - interactions between climate change, ship traffic, industry, urban waste, pollutants, fish farms, and infectious diseases

There is a fine balance between creating sustainable value and negative influence on the ecosystem!

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About the Nautilus21 project

- Strategic university college project (SHP)
- Submitted to Norwegian Research Council 12 February 2014
  - response expected within 1 July 2014
- Total budget 24 MNOK over 3 years (2015–17)
- Collaboration between Faculty of Engineering and Natural Sciences (AIR) & Faculty of Life Sciences (ABF) at AAUC
- Interdisciplinary approach: oceanography, epidemiology, natural sciences, cybernetics, artificial intelligence, software engineering, simulation and visualisation, ...
- Inspiration: Jules Verne's Captain Nemo and his high technology ocean research lab: the submarine Nautilus

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AAUC strategy

- AAUC strategy plan for 2012–15 prioritises
  - sustainable marine food production and health
  - simulation and visualisation
- AAUC plans 138 MNOK Centre for Ocean Space Innovations
  - applied for 53 MNOK governmental funding
  - centered around ocean space simulator as integrated tool for design, prototyping, simulation, and visualisation
  - interfaculty and interdisciplinary
- AIR faculty's strategy for 2013–17 focuses on
  - simulation and visualisation (S&V) as generic tools for value creation and efficiency in private sector and public management
  - new MSc in S&V from autumn 2014
  - state-of-the-art 3D S&V lab heart of MSc and COSI

Nautilus21 is a core element in the AAUC strategy!

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Current state-of-the-art ocean space models

- Generally devoted to large geographical ocean areas
- Coarse and static spatial and temporal resolutions
- Examples: SINMOD[4] and ROMS[5] oceanographic models for coastal areas with spatial resolution in range 4 km to 160 m
- Requirements for Norway's coast and fjords:
  - scalability in space and time $\Rightarrow$ ability to zoom in and out along both space and time axes depending on processes and areas under examination
  - visualisation $\Rightarrow$ ability to depict graphically a variety of simulation aspects to enhance understandability and usability

[4] http://www.sinmod.no
[5] https://www.myroms.org

Bioaccumulation of chemicals in marine food chain

- Chemicals are dispersed into rivers, fjords, oceans ⇒ may be toxic to algae, shellfish, fish, animals, humans
- Brominated flame retardants (BFRs)
  - particularly prone to bioaccumulation in long and lipid-rich food chains
  - detected in Norwegian blood samples since 1980s
  - some are harmful and may also have environmental impact
- Case study 1: Borgundfjorden
  - surroundings include residential and industrial areas
  - spawning area for coastal cod stock
  - fish and crustaceans used for human consumption
  - pollution include BFRs, hexabromocyclododecane, mercury

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Risk of pollution and diseases from fish farm industry

- Industrial aquaculture activity may result in
  - organic and chemical pollution ⇒ toxicity and bioaccumulation
  - viral and parasitic diseases ⇒ negative interaction with wild stock
- High concentration of pathogenic organisms in fish farms
- Risk of negative effects on economy and reputation
- Case study 2: Storfjorden
  - surroundings include agricultural activity and some urban settlements
  - extensive fish farming activity
  - several wild salmon stocks

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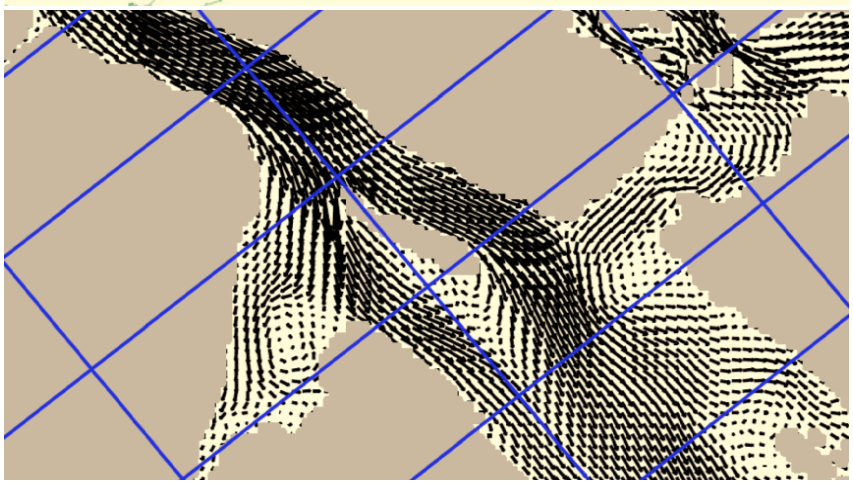
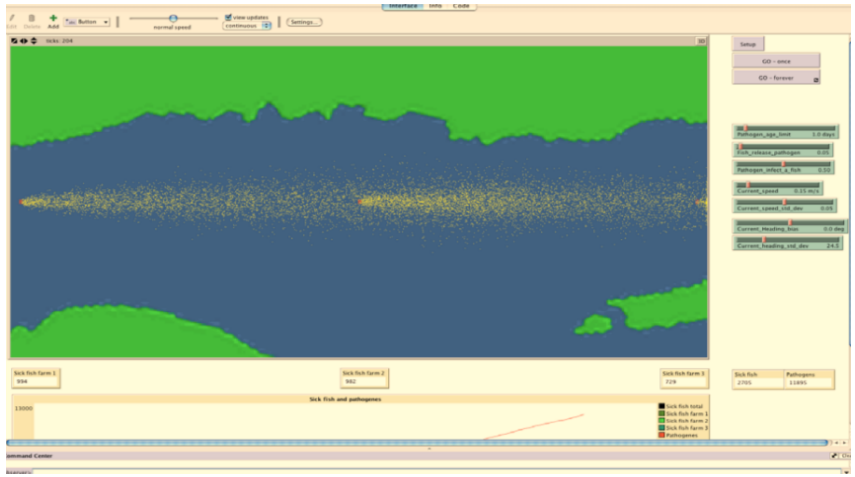
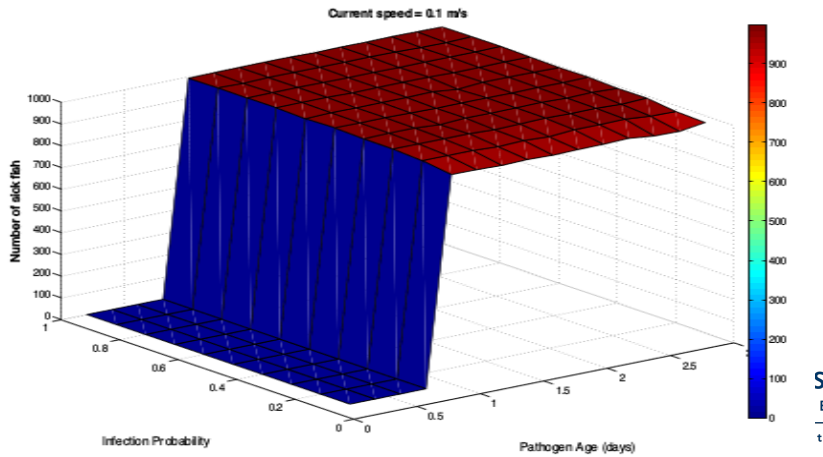
Example of agent-based simulation study

Pathogen transmission in Romsdalsfjorden







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Conflicts of interest in fish farm industry

- There is a tradeoff between positive and negative effects
- Minimise cost and maximise profit $\Leftrightarrow$ pollution and diseases
- How to combine sustainable management and exploitation of marine ecosystems?
- Answer: must balance tradeoff . . .

. . . therefore, a long term project goal is:
Nautilus21 shall contribute to knowledge for ecologically and economically sustainable harvesting in coexistence with industrial utilisation of the fjords guaranteeing safe and high quality seafood.

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Objectives

- Primary objective: *develop a generic, integrated, and scalable 3D ocean simulator for scientific exploration and management of Norway's coastal waters and fjords.*
- Secondary objectives:
  1. gather marine data and explore interactions between oceanographic data and human activity
  2. integrate and refine data and existing models and construct new models for simulation
  3. implement a generic, integrated, and scalable 3D ocean simulator for simulation and visualisation of marine processes and interactions
  4. develop domain-specific modelling languages and high quality user interface for non-technical domain experts

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Hypothesis

We hypothesise that by means of swarm theory and swarms of self-adapting intelligent ocean models, we will make our 3D ocean simulator generic, integrated, and scalable:

- generic: easy to adapt and modify to different ocean area case studies and topics of interest
- integrated: serve as integrator of historic and current scientific knowledge, data, and models
- scalable: easy to scale both to micro and macro levels depending on user needs, while intelligently scheduling computational load to optimise simulated area of interest

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Project management

- Project manager: Dr. Robin T. Bye, automation, AIR, AAUC
- Steering group:
  - Roar Tobro, director, AAUC
  - Prof. Harald Yndestad, S&V, AIR, AAUC
  - Dr. Vidar Aspehaug, Patogen Analyse AS
  - Sigrid Roald, Ålesund kommune
- Interdisciplinary project team from AIR and ABF at AAUC
- 4 work packages (WPs) for theoretical and practical aspects:
  1. WP1 oceanography and biology
  2. WP2 modelling and data analysis
  3. WP3 simulation and visualisation
  4. WP4 model-driven software engineering

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Project team, equipment, and budget

- Matrix organisation in WPs across faculties (20 MNOK)
  - $4 \times 100\%$ full research positions (PhD students)
  - $4 \times 25\%$ head of WP positions $+ 25\%$ extra research position
  - 16% project manager position
  - 250 hours hourly-based research
- Equipment (1 MNOK)
  - server park, marine measurement equipment/sensors, equipment for biology lab
- Other operating expenses (1 MNOK)
  - conference/networking, meetings, seminars, workshops, demos
- Entirely funded by AAUC (2 MNOK)
  - S&V lab, biology lab, steering group, partners
- Total budget 24 MNOK (6 MNOK own funding)

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Partners

- Public partners:
  - Kystverket
  - Ålesund kommune
  - Sula kommune
- Private partners:
  - Møreforsking AS
  - Patogen Analyse AS
  - Havbrukstjenesten AS
  - Marine Harvest AS
  - Salmar Organic AS

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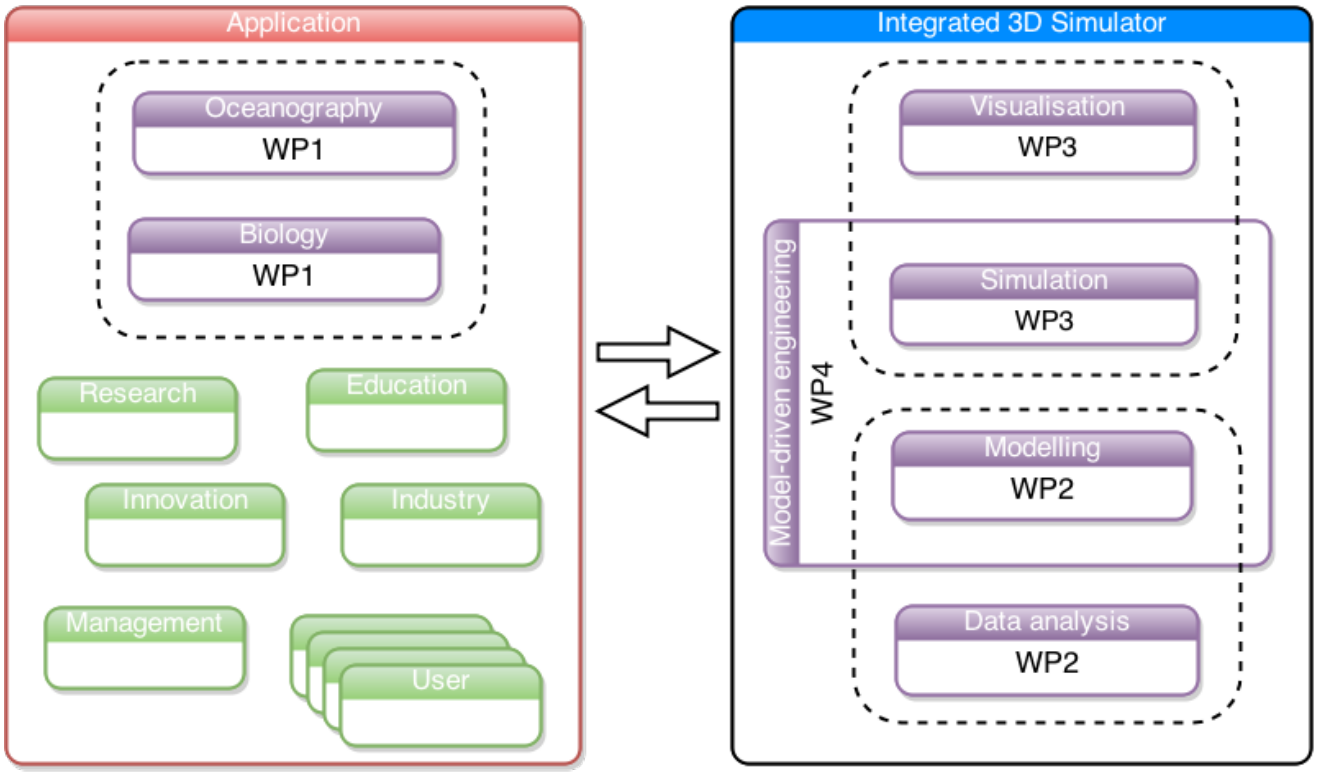
Graphical overview of WPs

Real-world problems and applications (WP1) as a catalyst for simulator development (WP2–WP4)



Aspects of modelling, simulation, and visualisation

- Models can be used for
  - representing reality (but are never perfect)
  - provide testable explanations for real-world phenomena
  - enable improvements in real-world, e.g. control system
- Simulation can be used for
  - model verification and validation
  - make predictions of future
  - test hypothetical what-if scenarios
- Visualisation can be used for
  - enhance understandability and usability
  - accommodate different user needs
  - focus on different simulation aspects

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WP1: oceanography and biology

- Head: Dr. Anne Stene, ABF, AAUC
- Provider of real-world data, knowledge, problems
- Examine effects of human activity on biological systems
- Two case studies (Borgundfjorden and Storfjorden):
  - collect oceanographic data (temperature, salinity, etc.)
  - review existing data and identify effects of pollutants
  - identify biotopes and establish models for microorganisms
  - test indicators of chronic stress & immune system function
  - identify concentration/distribution of pollutants/pathogens
  - make plan for system of automatic submarine registration units

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WP2: modelling and data analysis

- Head: Dr. Hamid Shaker, AIR, AAUC
- Model case study fjords using three principles:
  1. use geography as reference system for information flow
  2. represent information as movable intelligent swarming agents
  3. agents report behaviour by means of virtual landscapes
- Tasks:
  - data integration and refinement
  - data mining
  - develop general intelligent models
  - develop specialised models for terrain, oceanography, marine fauna, marine ecosystems
  - develop virtual landscapes

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WP3: simulation and visualisation

- Head: Dr. Robin T. Bye, AIR, AAUC
- Verification and validation of WP2 models
- Emphasis on being generic, integrated, and scalable
- Tasks:
  - create storage and management system
  - design and implement simulator core
  - develop Nautilus parallel agent simulator engine (NPASE)
  - investigate state-of-the-art 3D graphics engines
  - integrate visualisation support in NPASE
  - investigate inclusion of augmented virtual reality

WP4: model-driven software engineering (MDSE)

- Head: Dr. Adrian Rutle, Bergen University College (ex-AAUC)
- Automatic software generation based on model transformation
- Develop techniques for model integration into WP3
- Describe modelling language by metamodels
- Parameterize simulator by a common meta-metamodel
- Tasks:
  - design new domain-specific modelling languages
  - develop methods for model transformations and
    a. code generation
    b. model integration
  - design and implement user interface
  - implement in-simulation user interaction

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Summary of project goals

- generic, integrated, and scalable 3D ocean simulator for modelling, simulation, and visualisation of Borgundfjorden and Storfjorden
  - link oceanographic data and human activity with biological research questions related to dispersal and movement of particles and effect on marine ecosystems
  - use real-world biological problems as a guide and driver for iterative design and development of simulator
  - generic and modular simulator, easy to extend to other marine areas
  - integrated simulator, integrate several types of models and systems
  - scalable simulator, zoom in/out on levels of details, systems, processes, and also scale its parallel performance

Challenges

The main challenges are:

- Analysis and refinement of huge amount of marine environmental data and numerous formats
- Development of sufficiently accurate models of complex interactions in coastal waters
- High computational processing demand during simulation and visualisation
- Interfacing and abstraction layers between components in simulator
- End product being generic and easily extendable to other research purposes

Conclusions

- *Have* done much necessary theoretical and applied background research
- *Have* interdisciplinary and competent project team
- *Have* relevant scientific, industrial, and public partners
- *Have* adequate infrastructure at AAUC
- Project's first stage use in oceanography and biology
- Future uses in research, education, innovation, public management, industrial purposes

Thank you for listening!

Questions?