Applied Optimization at SINTEF

Chief Scientist, Dr. scient. Geir Hasle
SINTEF ICT, Oslo, Norway

Invited talk

University of Jyväskylä

October 9 2008

Outline

- SINTEF and SINTEF ICT
- Applied mathematics at SINTEF
- Applied optimization at SINTEF
- Transportation logistics

Technology for a better society

SINTEF

- An Independent Multi-Disciplinary Contract R&D Organisation
- Established in 1950
- Among the Largest CRO in Europe

Vision:

- Technology for a better Society

Business Concept:

- To meet the needs for Research-Based Innovation and Development for the Private and Public Sectors

SINTEF

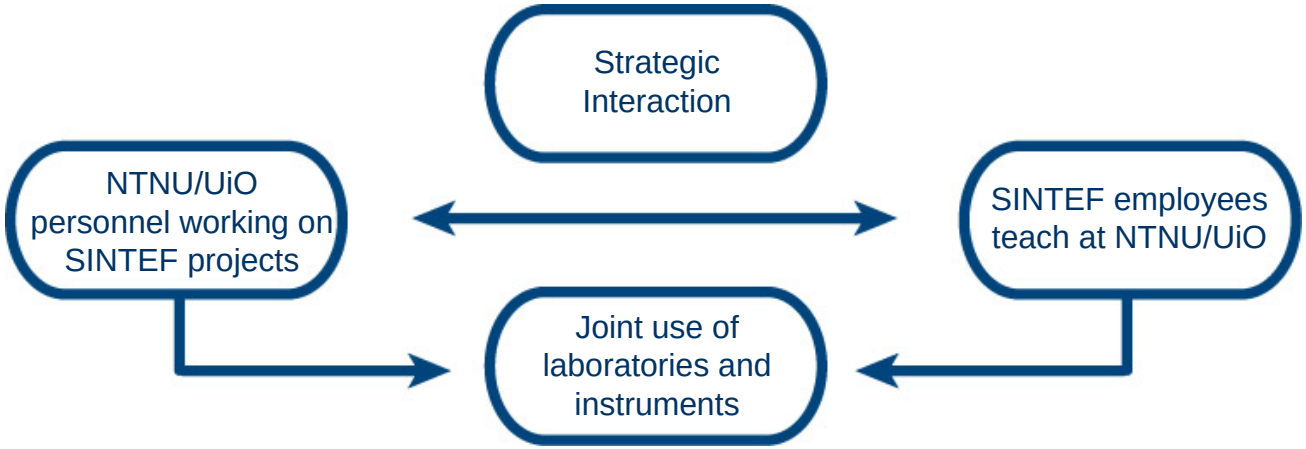
- A Norwegian contract research institute
- More than 2000 employees
- Science and engineering – social sciences, health care

- Strategic, long term, basic research
- Contract Research
- Consultancy
- Commercialization
- Spin-offs

Our strategic partners

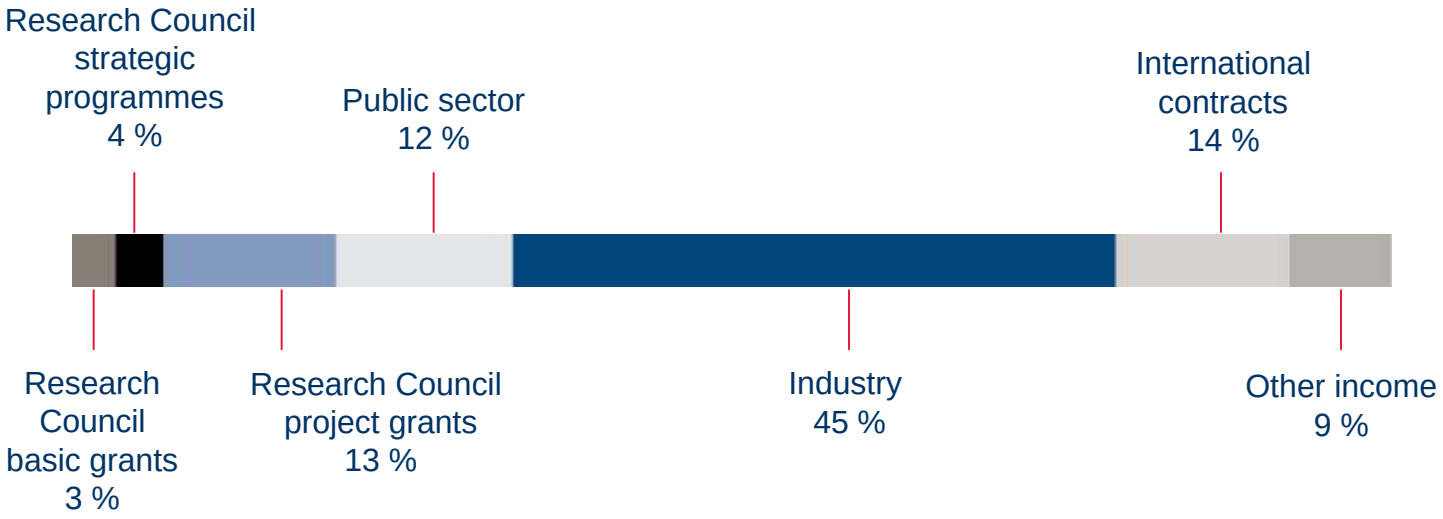
- The Norwegian University of Science and Technology, NTNU
  NTNU is a centre for technological education and research in Norway, with a solid foundation in the natural sciences.

- The University of Oslo, UiO
  The University of Oslo is Norway's largest and oldest institution of higher education.



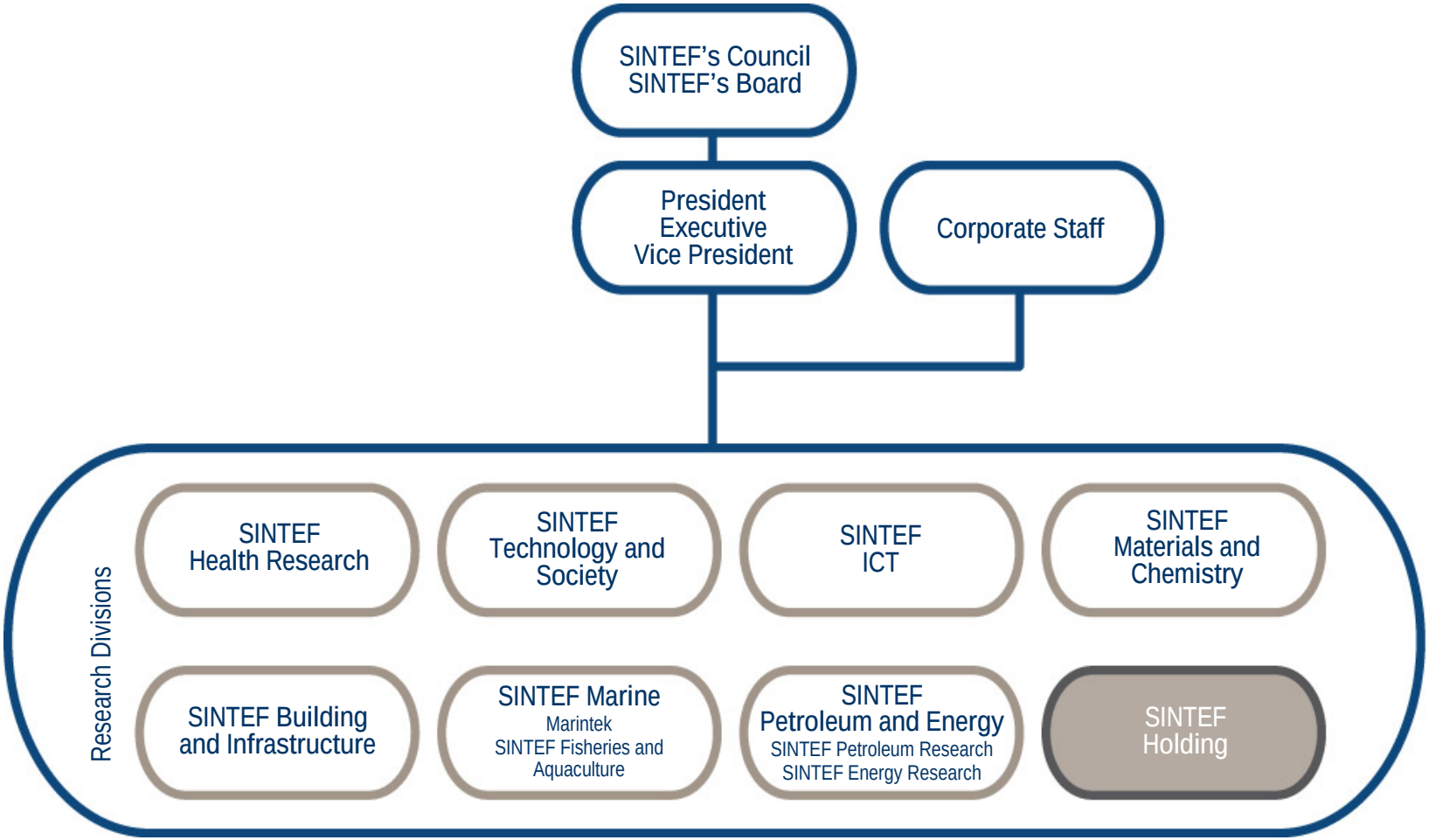
NTNU/UiO and SINTEF Collaboration in R&D

SINTEF revenues

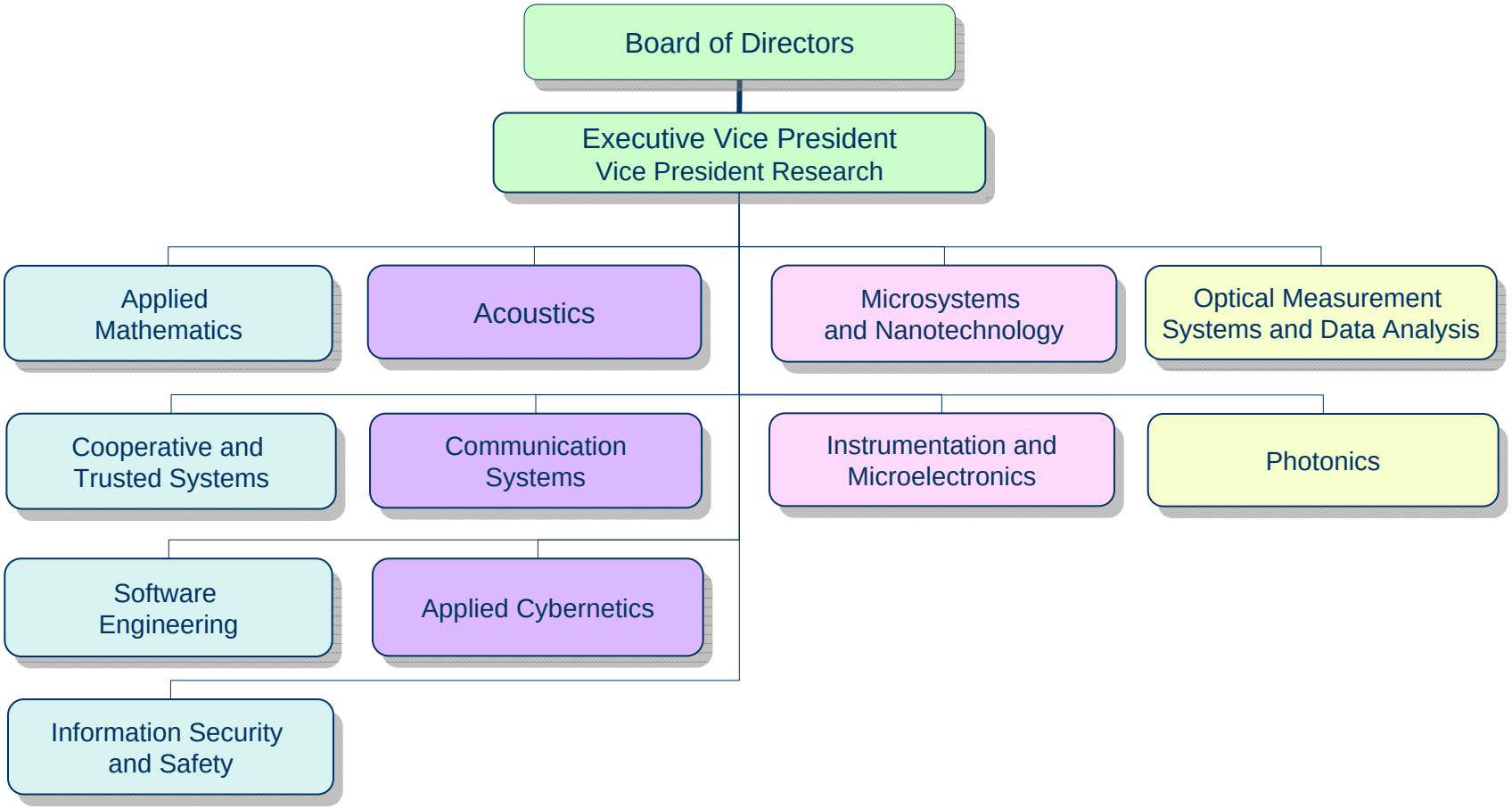


The SINTEF Group turnover in 2007: NOK 2.3 billion

SINTEF


SINTEF's Council
SINTEF's Board
President
Executive
Vice President
Corporate Staff
Research Divisions
SINTEF
Health Research
SINTEF
Technology and
Society
SINTEF
ICT
SINTEF
Materials and
Chemistry
SINTEF Building
and Infrastructure
SINTEF Marine
Marintek
SINTEF Fisheries and
Aquaculture
SINTEF
Petroleum and Energy
SINTEF Petroleum Research
SINTEF Energy Research
SINTEF
Holding

SINTEF ICT Organization



Key figures for SINTEF ICT

- Number of employees 269
  - Scientists 227
  - Engineers and technicians 22
  - Administrative staff 20
- Annual Turnover NOK 267 million

Research at SINTEF ICT

Atle jobber ikke i NASA

Men det gjør forsknings-resultatene hans

Høyt over oss suser romstasjonen ISS avgårde. Den har hjertebarnet til SINTEF-forsker Atle Honne om bord: gassmåleutstyr som skal hindre at astronauter puster i seg helse-farlige stoffer på jobben.

Måleteknikken er velegnet også på jorda. Der kan den overvåke alt fra industri-prosesser til inneklimaet i ubåter og andre utsatte miljøer.

NACRE AS – A SINTEF spin-off

Noise protection communication headset - QUIETPRO
Company sold for ¾ billion NOK in 2007

Jakten på milliardbedriften

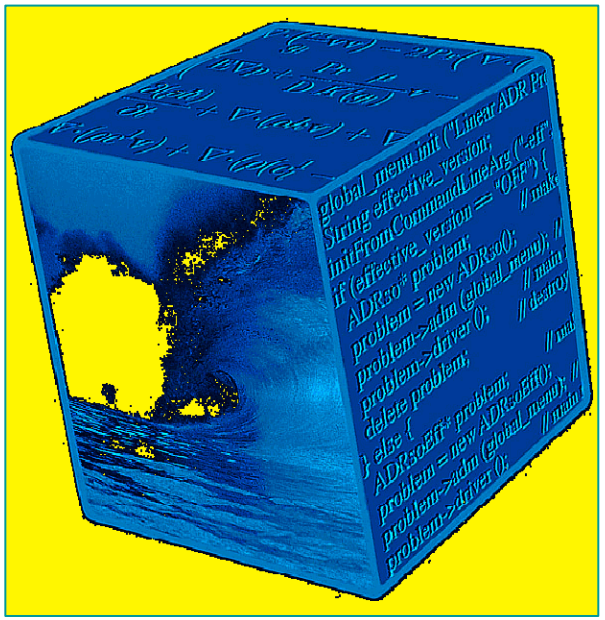
Utlendingene kjøper bedrifter for milliarder i Trondheim. Hva er det som skjer i byen?

Publisert 13.06.2007

SINTEF ICT Applied Mathematics

- SINTEF ICT
  - provides research-based expertise, services and products ranging from microtechnology, communication and software technology, computational software, information systems, and security and safety.

- The Department of Applied Mathematics consists of 38 employees
  - Researchers
  - Postdocs
  - PhDs
  - Software engineers, programmers



- Five research groups

SINTEF ICT Applied Mathematics

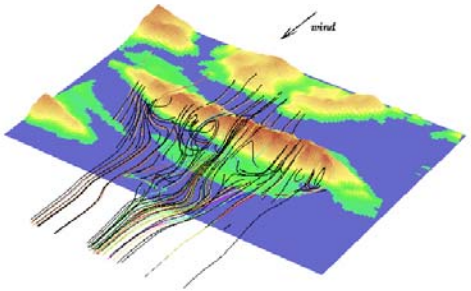
- Utilizes **modelling** and **software engineering** to solve industrial problems
- Geometry
  - Algebraic geometry, approximation theory, multiresolution methods, spline technology
- Simulation
  - Computational fluid dynamics, PDE-based image processing, high-performance computing, wave modeling, optimal control and shape design
- Optimization
  - linear and nonlinear programming, discrete optimization, heuristics and metaheuristics, constraint programming

The research groups

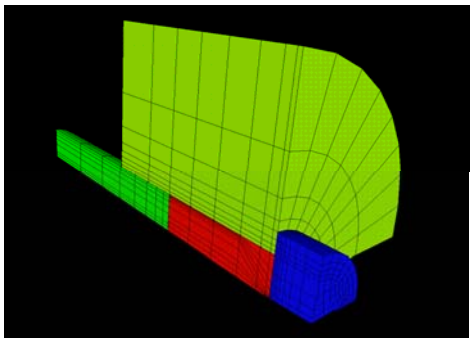
- The ***Geometry group*** (Oslo) focuses on computational geometry, visualization, and development of 3D technology for the IT industry.
- The ***Simulation group*** in Trondheim focuses on developing robust and efficient numerical methods for computational mechanics and geophysical flows.
- The ***Simulation group*** in Oslo develops robust and efficient computational methods for subsurface flow (petroleum, CO2, groundwater).
- The ***Optimization group*** (Oslo) develops optimization methods for applications within, among others; transportation, (maritime) logistics, and planning health sector.
- The ***Heterogeneous computing group*** (Oslo) performs research on multicore and data-stream processing.
- Active partner in the ***Centre of Mathematics for Applications***, a national centre of excellence at the University of Oslo.
- Contributes to the ***Centre for Integrated Operations*** in the Petroleum Industry, a national centre for research-based innovation at NTNU. Key strategic research areas include multiscale simulation and isogeometric analysis.

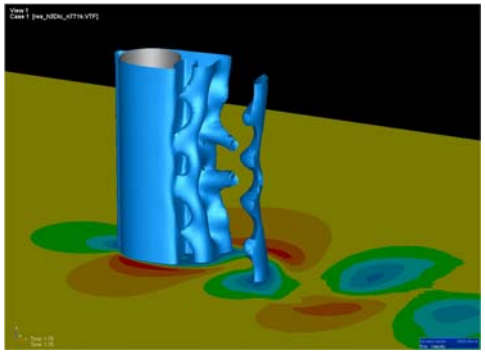
Simulation group (Trondheim)

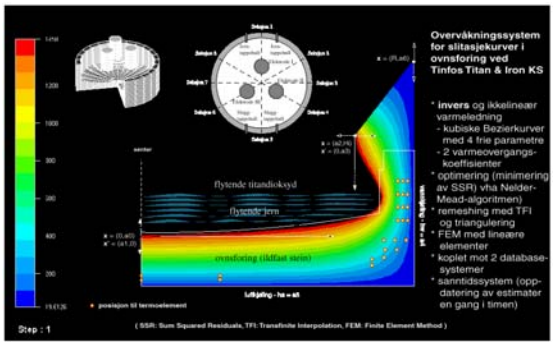
Methods
in focus



- Mathematical modeling
- Geometrical modeling
- Finite element methods
- Adaptive methods
- Parallel algorithms
- Coupled problem
- Inverse problems
- Turbulence







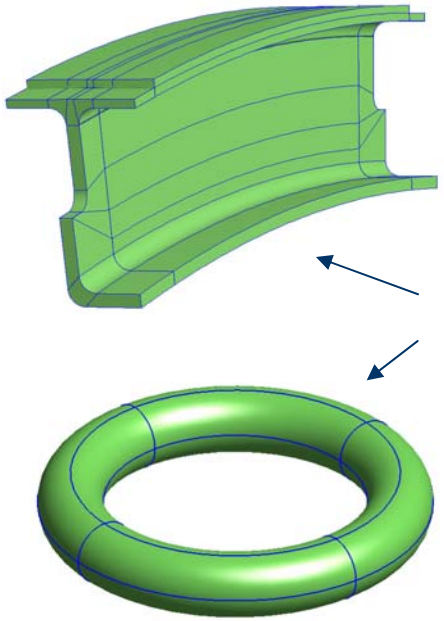
ICADA: Integrated Computer Aided Design and Analysis

Main objectives

Build competence in Norway for taking advantages of Integrated Aided Design and Analysis (ICADA) based on coherent representation for geometry and analysis

Partial objectives

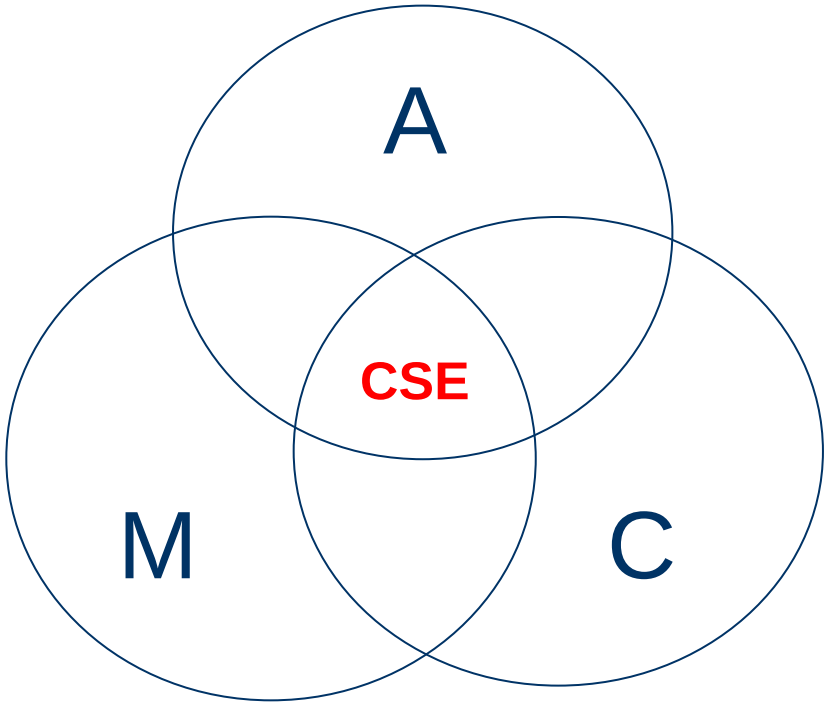
1. Make transfer of models between design and analysis more robust and efficient
2. Build competence in Norway for utilizing spline finite elements in industry
3. Make adaptive spline finite element methods suitable for practical use in industry



Exact geometry

Computational Science and Engineering (CSE)

Interplay between: **M**athematics – **A**pplications – **C**omputer science

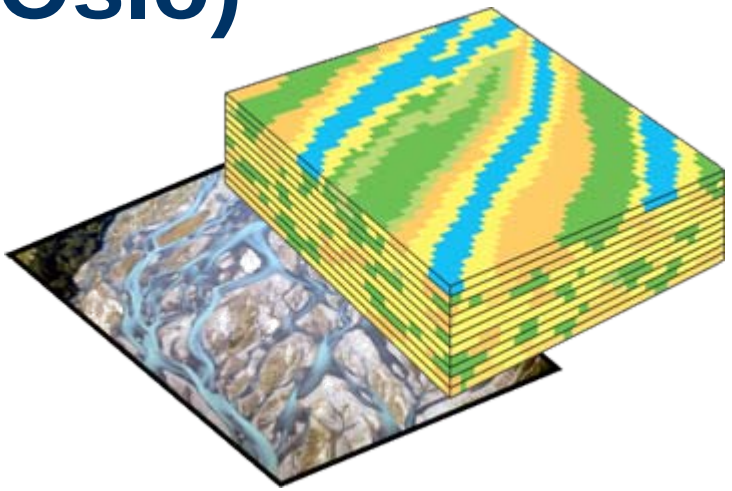


- **Applications**: Biology, chemistry, marine technology, materials, mechanics, medicine, nanotechnology, petroleum, physics, engineering, operations research
- **Mathematics**: Models, analysis and numerical methods
- **Computer science**: Algorithms, software development and hardware

***CSE** represents the development and use of computational methods for solving scientific and engineering problems*

Simulation Group (Oslo)

- 4 researchers
- 3 postdocs
- 1 PhD student
- 3 software engineers



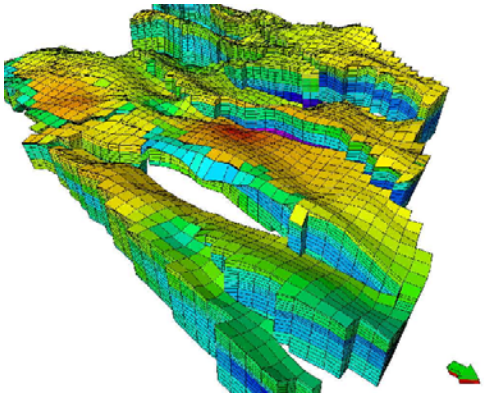
Collaboration with national and international partners in industry and academia

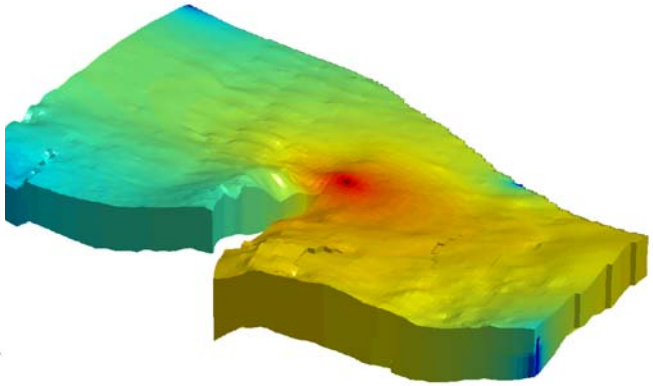
Research vision:

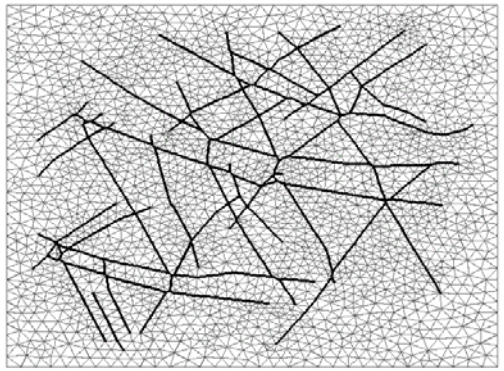
Direct simulation of flow on complex grid models of highly heterogeneous and fractured porous media
- bypassing the need for upscaling

Applications

- Validation during development of geological models
- Fast simulation of flow on industry grids
- Optimization of production, well placement, etc.
- History matching
- Geological storage of CO2 (CCS)







Selected projects

Research projects partly funded by the RCN

- GeoScale II– Reservoir simulation on a geological scale
  - Strategic institute program, 2008-2010
  - Partners: NTNU, UoB, UoO, Schlumberger, StatoilHydro
- Multiscale simulation of highly heterogeneous and fractured reservoirs:
  - KMB project, 2006-2009, 9 MNOK
  - Partners: NTNU, Shell
  - 1 PhD
- Geological storage of C02: mathematical modelling and risk assessment
  - KMB project at UoB, 2007-2011, 21 MNOK
  - Other partners: CIPR, Princeton, Stuttgart, Shell, StatoilHydro
  - 1 postdoc

Industry projects

- Multiscale-streamline simulation of highly heterogeneous and fractured reservoirs:
  - BIP project, 2006-2008
  - Project management: Schlumberger IS
  - 1 postdoc
- New two-phase solver in xModel/SBED/ SBEDStudio
  - StatoilHydro
  - Geomodelling (Canada)
- Fast evaluation of flow patterns
  - Confidential client (USA)
- Near wellbore and completion hydraulics
  - Confidential client

Heterogeneous Computing Group

- *Heterogeneous computing is the strategy of using multiple types of processing elements within a single workflow, and allowing each to perform the tasks to which it is best suited.*

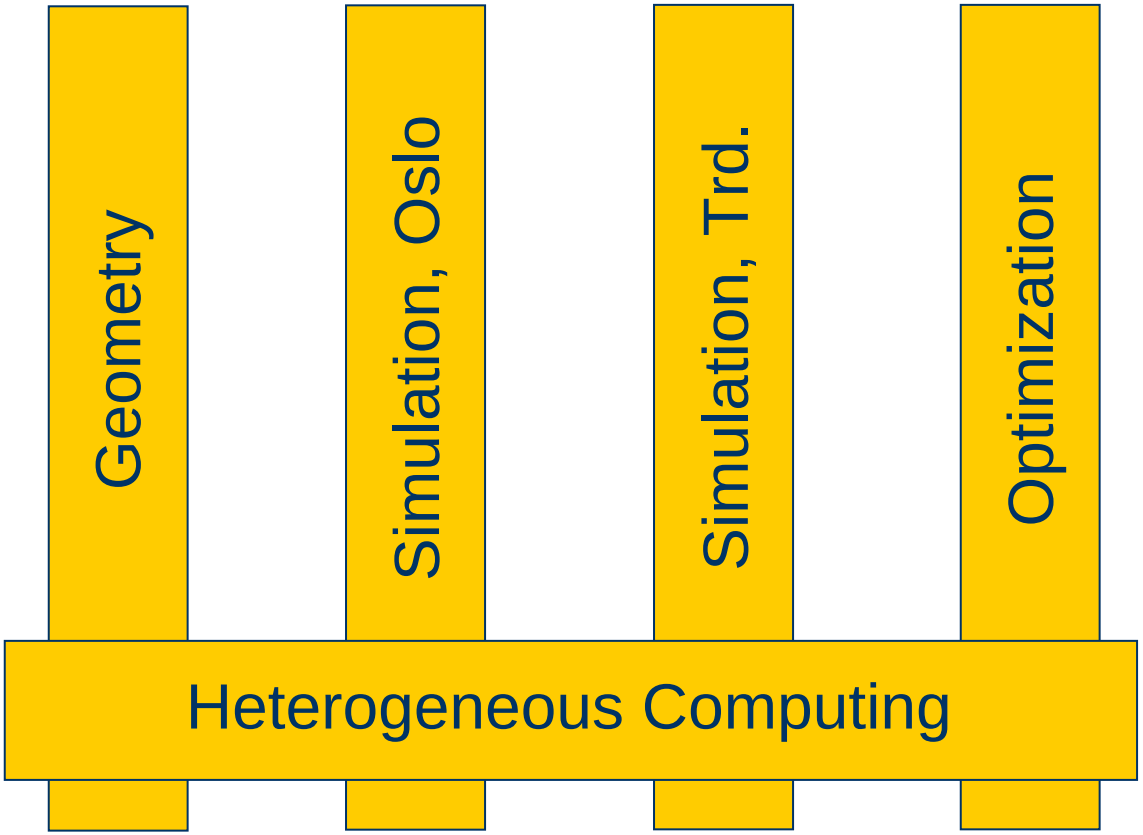
- hybrid computing
- accelerated computing
- General-Purpose Computing using GPUs (GPGPU)
- GPU computing

Moore's law (1965) and The Beach law (Gottbrath et al. 1999)

- *"The number of transistors on an integrated circuit for minimum component cost doubles every 24 months"*
  - Seems to hold true still
  - Transistor density roughly proportional to processor performance
- Growth in core clock frequency stagnated
  - Until recently (2004) increases in processor performance relied heavily on the increase of core clock frequency
- Stagnation of growth in performance of sequential code
  - Until now industry has experienced increasing value from their existing code base, with relatively little effort.
  - The *Beach law** now obsolete – your sequential code will probably not run faster next year
- Demand for parallelization of software

**Until recently one way of doubling the performance of your code was to wait 2 years (go to the beach) and then buy a new computer.*

SINTEF ICT, Dep. of Applied Mathematics



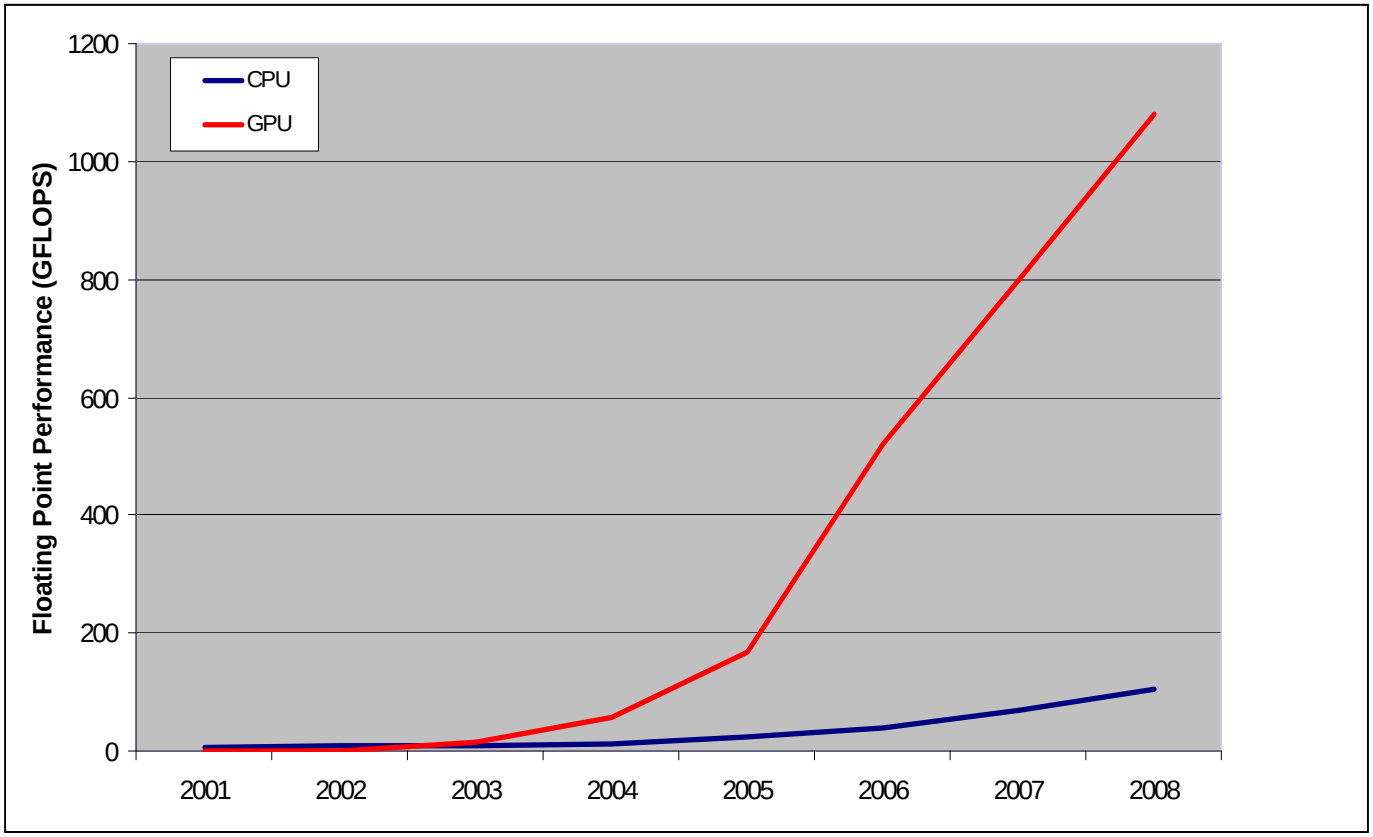
Heterogeneous Computing Group

- HC group: 10 scientists and Ph.D. students
- Started with GPU computing in 2003
- What we do:
  - Develop new heterogeneous methods with special focus on geometry, simulation and visualization.
  - Refactoring code for optimal performance on a HC.
  - Work in cross-disciplinary teams with domain specialists to create the most effective algorithms.
- Architectures:
  - Data-parallel
  - Shared memory, multi-core
  - Cluster, HPC

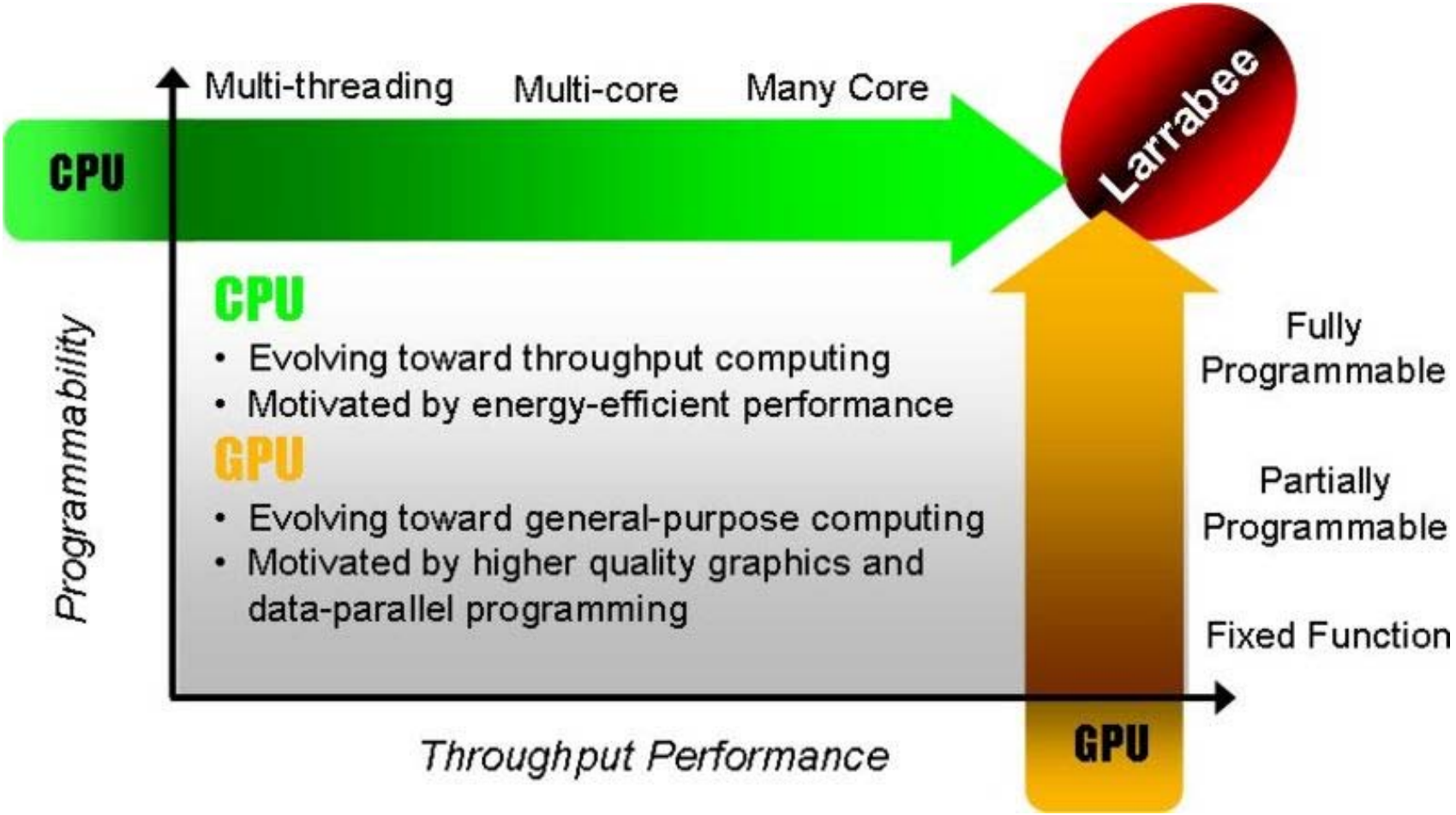
Target Architectures – Graphic Processing Units (GPUs)

Graphics card

- Massive parallel architecture. Data-parallel processing
- Typically 10-100 times speedup

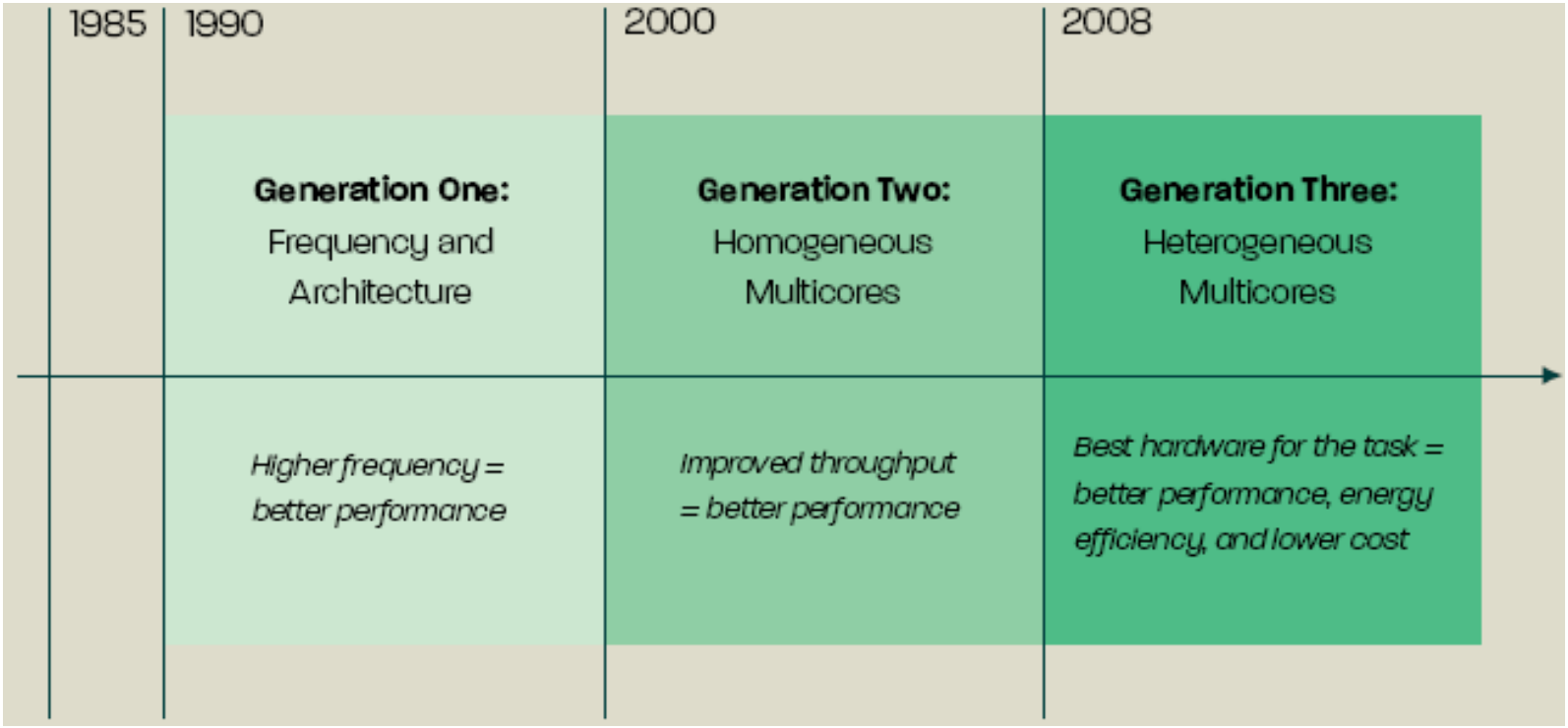


Target Architectures – Intel Larrabee



Target Architectures – AMD Fusion

- A computer will include general and specialized processors.
- A processor will be chosen to handle a given task based on its ability to provide optimal performance



Heterogeneous Computing Group - Partners

- Industrial users
  - **StatoilHydro:** seismic processing
  - **General Electric:** GPU processing
  - **Detec:** image processing
  - **Roxar:** visualization
- Funding agencies
  - **Research Council of Norway:** computational methods within simulation, geometry and visualization.
  - **EC:** Collaborative Project, Security program, Picture analysis, surveillance
- Hardware vendors
  - **Nvidia**
  - **AMD**
  - **Intel**
  - **IBM**

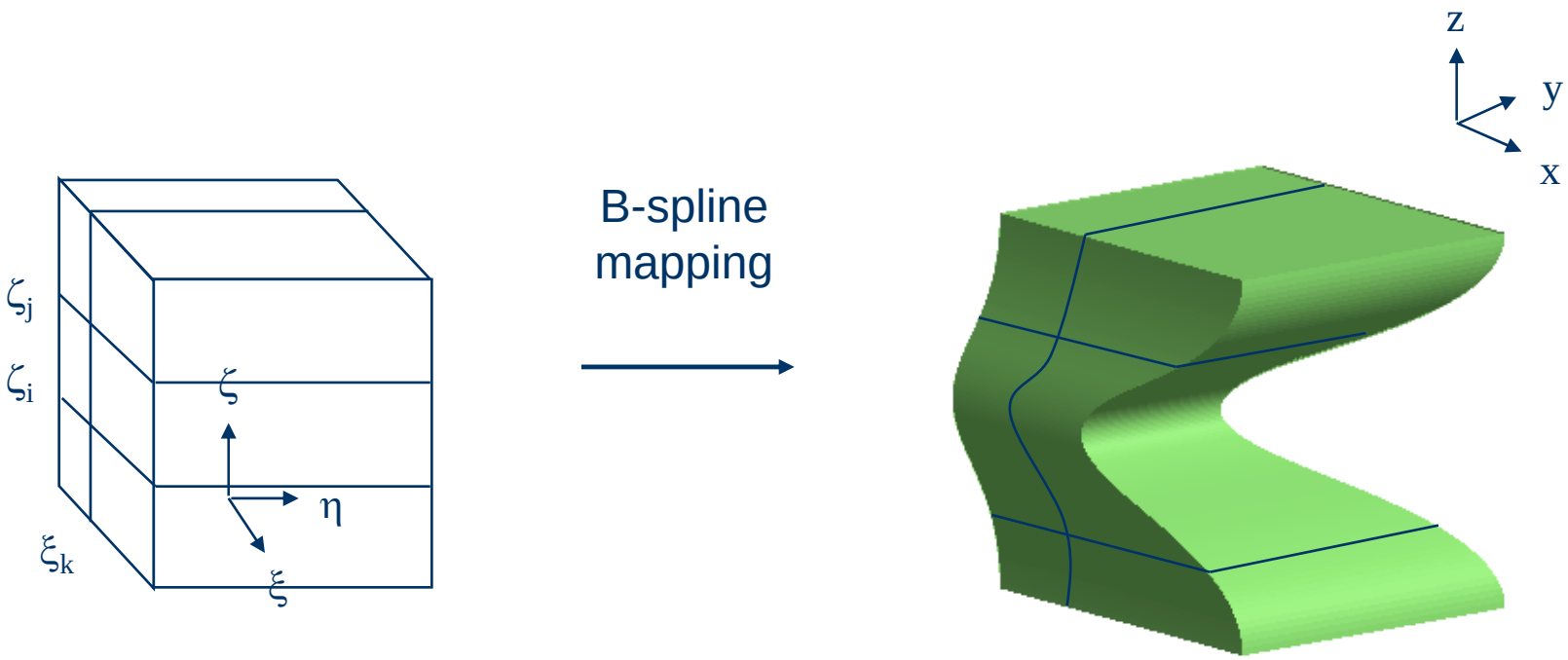
Geometry Group

- 5 research scientists
- SAGA – Shape Algebra and Geometry. Marie-Curie Initial training network. 2008-2012. SINTEF coordinator http://www.saga-network.eu/. PhD and Post. Doc. Fellowships.
- Focus K3D – Coordination Action within Shape and Knowledge Technology (semantics) 2008-2010. http://www.focusk3d.eu/
- Industrial project on CAD-technology for CoCreate (Parametric Technology)
- Large activity on isogeometry

Isogeometric representation and analysis

- Current representation of geometric models in CAD (Computer Aided Design) is based on ideas from 1980s.
- Current representation of models within FEM (Finite Element Analysis) is based on ideas from 1970s
- Extremely expensive for industry to transfer models between CAD and FEM processes
  - CAD-representation is a patchwork of high quality surface pieces where adjacent patches match within predefined tolerances.
  - FEM-representation is made from volumes where adjacent volumes match exactly. The outer surfaces of the volumes not of same geometry quality as CAD-models
- High potential for improvements in industry
  - Blocked until now by CAD-companies and the legacy of models using exiting technology

Iso-geometric representation



- Parametric volume representation using B-splines both for CAD and FEM

Large SINTEF Activity with isogeometric representation and analysis

- Isogeometry. Norwegian project for improving the mathematics used in the processes between CAD and FEM. (2008-2011)
- ICADA. Norwegian project looking at the use of splines elements (mathematics of CAD) in FEM.(2008-2013)
- Exciting. EU-project looking at the use of isogeometric analysis within the transport sector. (2008-2011)

- Total SINTEF activity 2008-2013 4 million EURO.

Group of Optimization

- 8 scientists, 1 software engineer
- Development of optimization models and algorithms
- Research, Development, ...
  - Planning, scheduling, routing, location, network optimization
  - Logistics, Transportation, Finance, Oil and Gas, Health, Forestry, Sports
  - Prototypes
  - Products, Components, Services
  - Decision Support Tools
  - Support and Maintenance
- Consultancy
  - Requirements
  - Quantitative Assessment of Improvement potential
  - Specifications, Tender
  - Surveys
  - Assessment of products, benchmark definition
  - Analysis based on optimization models
- Spin-offs

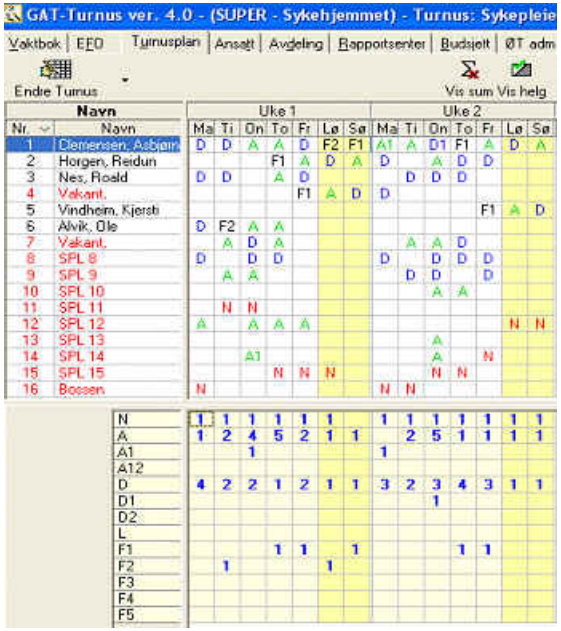
Example : Finance

- Clearing system, VPS owned by Oslo Børs
- Clearing of all trades at Oslo Stock Exchange, twice a day
  - Clearing at 2008-08-19: 153 501 transactions, total value of NOK 145 billion
- Rather critical ...
- Advanced mathematical model that maximizes total value of all trades
- Constraints and regulations
- SINTEF responsible for maintenance and development of optimization kernel
- Strategic relationship

Example : Health sector

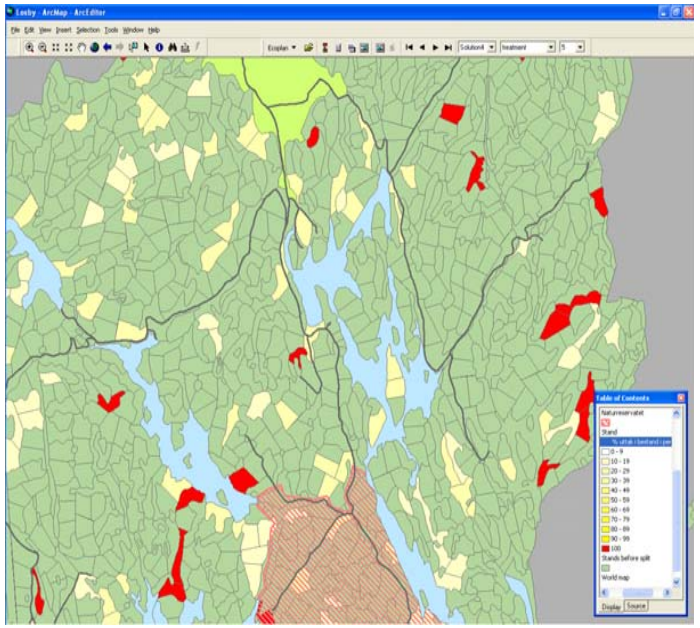
- SINTEF has developed a roster optimizer that is integrated in the crew scheduling software tool GAT-Turnus of GAT-Soft AS
- Generates rosters that satisfy health and safety requirements
- Possibility for manual planning before / after optimization

- Further work
  - Better optimization
  - General wishes
  - Individual wishes
  - Temporal wishes



Example : Forestry

- Creating treatment plans for all stands for the next 100 years
- The objective is to maximise the income to the forest owner
- Must satisfy several constraints
  - Given harvest profile
  - Maximum area of clear cut patches
  - Greenup-constraints
  - Visual restrictions
  - Minimum share of old and young forest



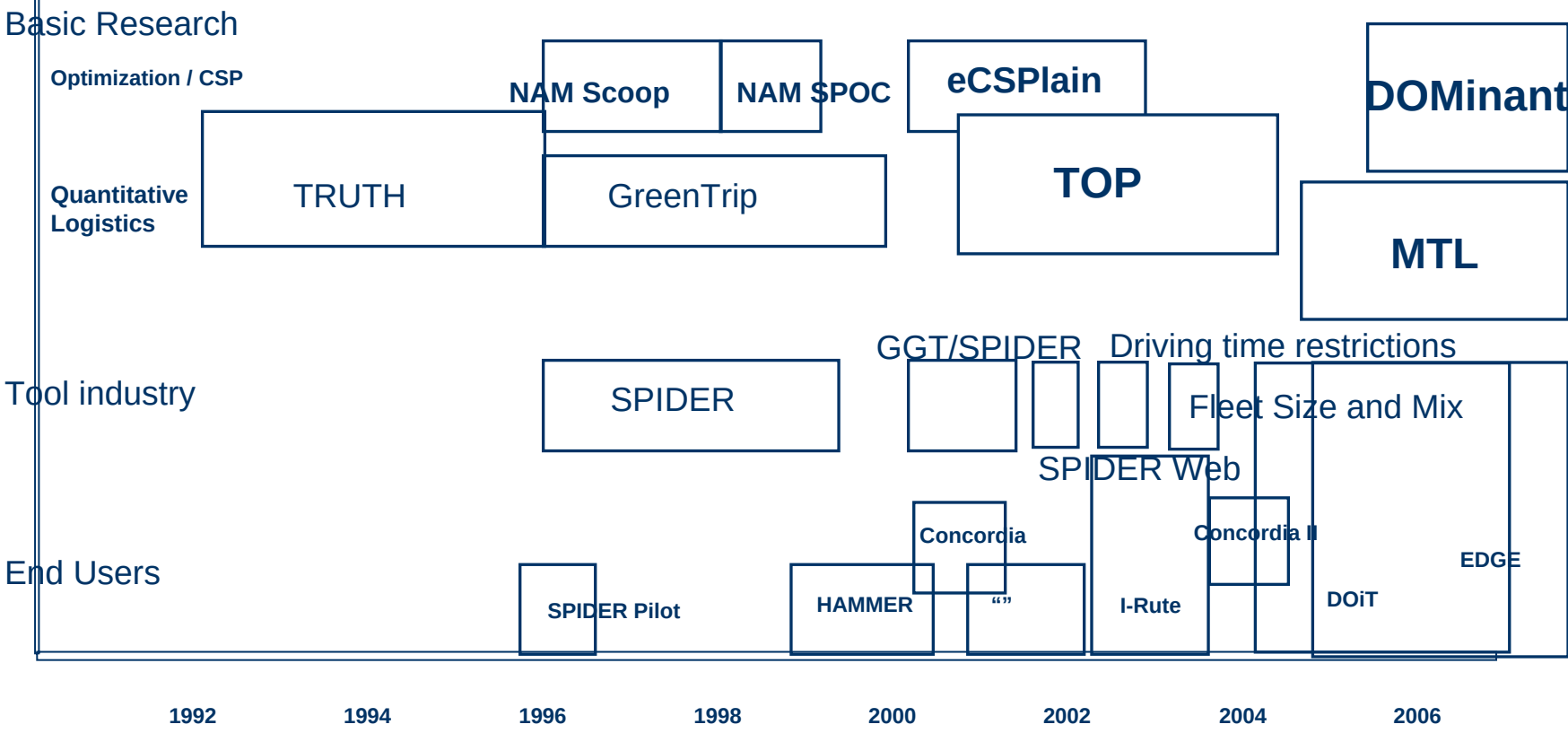
Example : Sports

- SINTEF made the schedule for the Norwegian premier division (football) 2008 season
- Two-stage process where the pattern is constructed first
  - No ”break” between round 1 and 2, nor between 25 and 26 (last round)
  - Minimum number of breaks
  - Minimum distance between ”same” match type (home and away)
  - Anti-teams
- Allocation of the teams to placeholder
  - Specific matches on specific days
  - Specific home or away - start and finish

Round	1	2	3	4	5	6	7	8	9	10	11	12	13
Team 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Team 2	1	14	3	4	5	6	7	8	9	10	11	12	13
Team 3	13	1	2	14	4	5	6	7	8	9	10	11	12
Team 4	12	13	1	2	3	14	5	6	7	8	9	10	11
Team 5	11	12	13	1	2	3	4	14	6	7	8	9	10
	10	11	12	13	1	2	3	4	5	14	7	8	9

SINTEF Applied Mathematics

Projects in Transportation Optimization



CONCORDIA > BUS

- One of the largest bus companies in Europe
- 4100 buses in Norway, Sweden and Finland

CONCORDIA BUS > SWEDEN

Employees	8,260
Buses	3,300

CONCORDIA BUS > NORWAY

Employees	1,140
Buses	440

CONCORDIA BUS > FINLAND

Employees	726
Buses	350

Concordia - Shift and vehicle rotation planning

- Integrated optimization problem
- Very rich model, local search and metaheuristics
- Bespoke planning kernel
- 2-5% reduction of costs (2-3 mill. SEK pr. region, 3 regions)
- 20-30% reduction of costs (driver preferences)
- Comparison: ”Industry standard” commercial tool Hastus

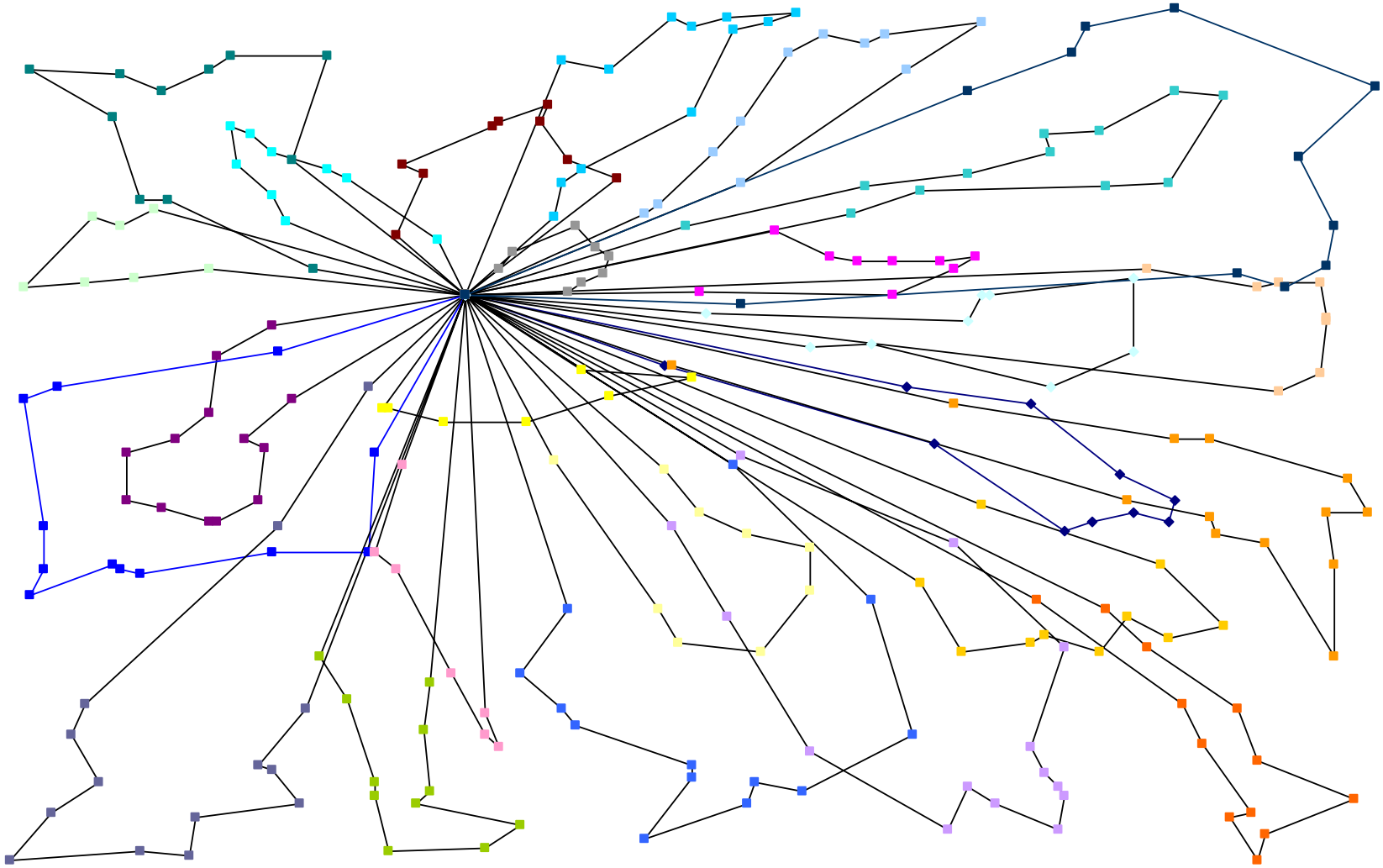
- 3 projects 2000-2004
- new project on driver rostering Nov’08

The Vehicle Routing Problem (VRP)

Given a fleet of vehicles and a set of transportation orders, find a minimum cost routing plan. That is: allocate each order to a vehicle, and for each vehicle, sequence the stops.

- The VRP central to efficient transportation management
- Applications
  - Distribution or pick-up of goods
  - Dial-a-ride
  - Municipal services
  - Repairman problem
  - Newspaper distribution
  - Waste management
  - Gritting, snow clearing
  - Tramp shipping, Industrial shipping, Liner shipping
- Very hard, discrete optimization problem

G-n262-k25: 5685 vs. 6119



Mathematical formulation of VRPTW
(vehicle flow formulation)

minimize $\sum_{k \in V} \sum_{(i,j) \in A} c_{ij} x_{ij}^k$ (1) minimize cost

subject to:

$\sum_{k \in V} \sum_{j \in N} x_{ij}^k = 1, \quad \forall i \in C$ (2) each customer once

$\sum_{i \in C} d_i \sum_{j \in N} x_{ij}^k \le q, \quad \forall k \in V$ (3) capacity

$\sum_{j \in N} x_{0j}^k = 1, \quad \forall k \in V$ (4) k routes out of depot

$\sum_{i \in N} x_{ih}^k - \sum_{j \in N} x_{hj}^k = 0, \quad \forall h \in C, \ \forall k \in V$ (5) flow balance for each customer

$\sum_{i \in N} x_{i,n+1}^k = 1, \quad \forall k \in V$ (6) k routes into depot (redundant)

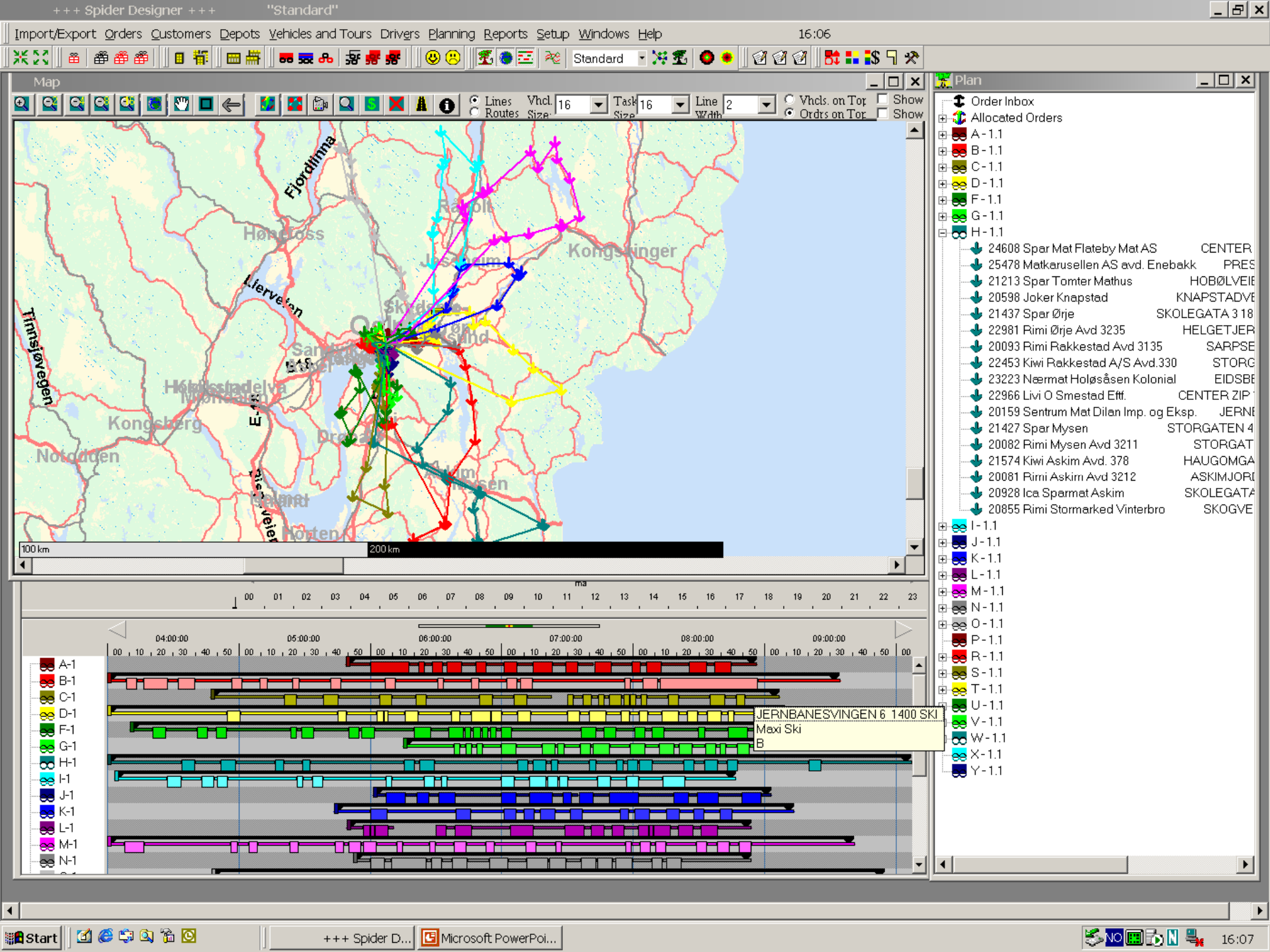
$x_{ij}^k (s_i^k + t_{ij} - s_j^k) \le 0, \quad \forall (i,j) \in A, \ \forall k \in V$ (7) start of service and driving time

$a_i \le s_i^k \le b_i, \quad \forall i \in N, \ \forall k \in V$ (8) start of service within TW

$x_{ij}^k \in \{0,1\}, \quad \forall (i,j) \in A, \ \forall k \in V$ (9) arc (i,j) driven by k

Research on Rich VRPs & related problems at SINTEF

- Industrial Contracts since 1995
- Strategic Research
  - European Commission FP III, IV, V (e.g., GreenTrip 1996-1999)
  - Norwegian Research Council (RCN)
  - Internal Projects, students
- Generic VRP Solver - SPIDER (1995→)
  - Commercialization from 1999
  - GreenTrip AS → SPIDER Solutions AS
- TOP Programme 2001-2004 (RCN) http://www.top.sintef.no/
  - Basic Research on Rich VRP and related problems
  - VRPTW
  - Shortest Path Problem in Dynamic Road Topologies
- Innovation Projects supported by Reserch Council of Norway
  - “I Rute” (2001 – 2004) Bulk transportation
  - “DOiT” (2004 – 2007) Stochastic and Dynamic Routing
  - “EDGE” (2005 – 2008) Huge Scale “Household” Routing
  - Effect (2008-2011) Distribution of media products
- Ship routing


+++ Spider Designer +++ "Standard"
Import/Export Orders Customers Depots Vehicles and Tours Drivers Planning Reports Setup Windows Help 16:06
Standard
Map
Lines Routes
Vhcl. Size: 16
Task Size: 16
Line Width: 2
Vhcls. on Top
Ordrs on Top
Show
Show
Fjordlinna
Hønefoss
Kongsvinger
Lierveien
Tinnsjøvegen
Kongsberg
Notodden
E-134
Horten
100 km
200 km
Plan
Order Inbox
Allocated Orders
A-1.1
B-1.1
C-1.1
D-1.1
F-1.1
G-1.1
H-1.1
24608 Spar Mat Flateby Mat AS CENTER
25478 Matkarusellen AS avd. Enebakk PRES
21213 Spar Tomter Mathus HOBØLVEIE
20598 Joker Knapstad KNAPSTADVE
21437 Spar Ørje SKOLEGATA 3 18
22981 Rimi Ørje Avd 3235 HELGETJER
20093 Rimi Rakkestad Avd 3135 SARPSE
22453 Kiwi Rakkestad A/S Avd.330 STORG
23223 Nærmat Holøsåsen Kolonial EIDSBE
22966 Livi O Smestad Etff. CENTER ZIP
20159 Sentrum Mat Dilan Imp. og Eksp. JERNE
21427 Spar Mysen STORGATEN 4
20082 Rimi Mysen Avd 3211 STORGAT
21574 Kiwi Askim Avd. 378 HAUGOMGA
20081 Rimi Askim Avd 3212 ASKIMJORD
20928 Ica Sparmat Askim SKOLEGATA
20855 Rimi Stormarked Vinterbro SKOGVE
I-1.1
J-1.1
K-1.1
L-1.1
M-1.1
N-1.1
O-1.1
P-1.1
R-1.1
S-1.1
T-1.1
U-1.1
V-1.1
W-1.1
X-1.1
Y-1.1
04:00:00
05:00:00
06:00:00
07:00:00
08:00:00
09:00:00
JERNBANESVINGEN 6 1400 SKI
Maxi Ski
B
Start
+++ Spider D...
Microsoft PowerPoi...
16:07

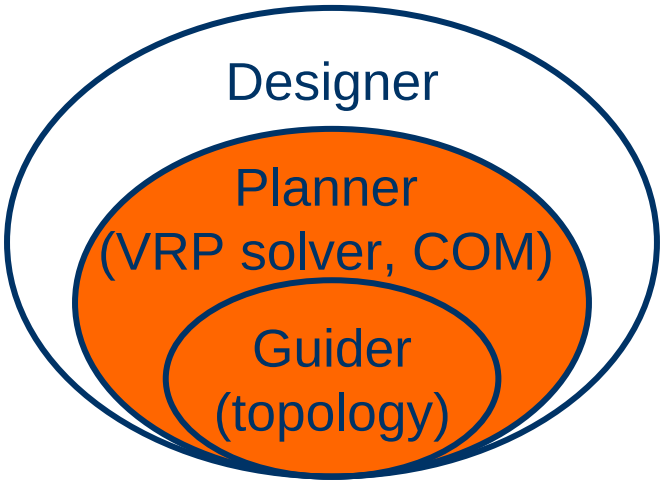
SPIDER Designer - Applications

- Local pickup and delivery (Schenker)
- Mail collection and distribution (Posten Norge)
- Newspaper distribution, 1st tier (Aftenposten, Dagbladet)
- Newspaper distribution, last mile (Aftenposten, Stavanger Aftenblad)
- Distribution of magazines (Bladcentralen)
- Distribution of fodder to farms (Landbruksdistribusjon)
- Collection of milk from farms (TINE)
- Distribution of bread (Bakers)
- Distribution of groceries (REMA 1000)
- Distribution of ice cream (Diplom Is; Hennig Olsen)
- Distribution of fuel oil (Hydro Texaco)
- Location analyses, depot (obnoxious facility location, Norsk Gjenvinning AS)
- Distribution of blood (Ullevål sykehus)
- Dial-a-ride, elderly, hospital patients (Nor-Link)

- Savings 5-35%, depending on application

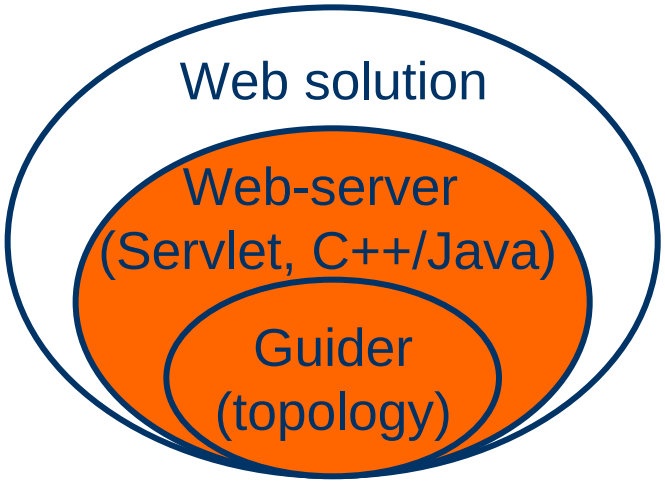
Products - architecture

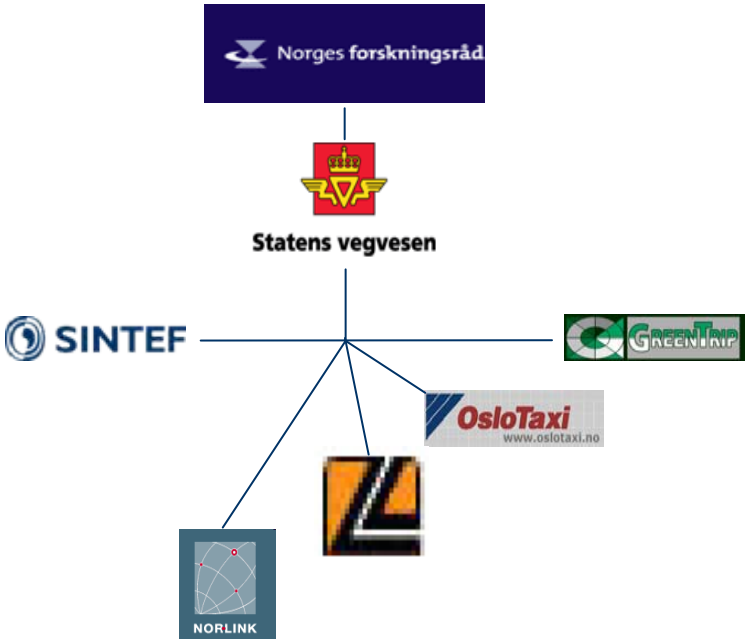
SPIDER Solutions AS



Distribution Innovation AS

Geomatikk AS

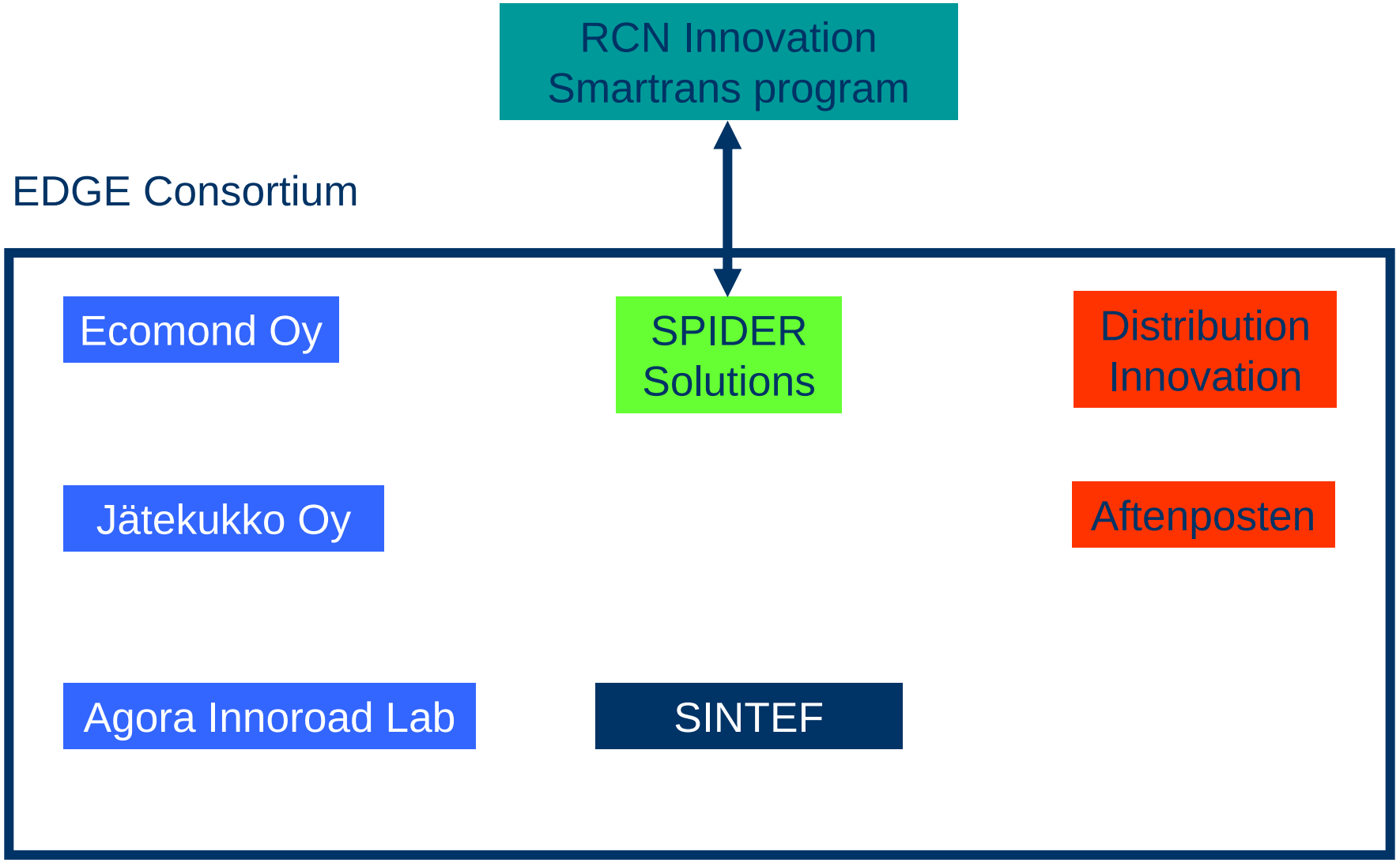


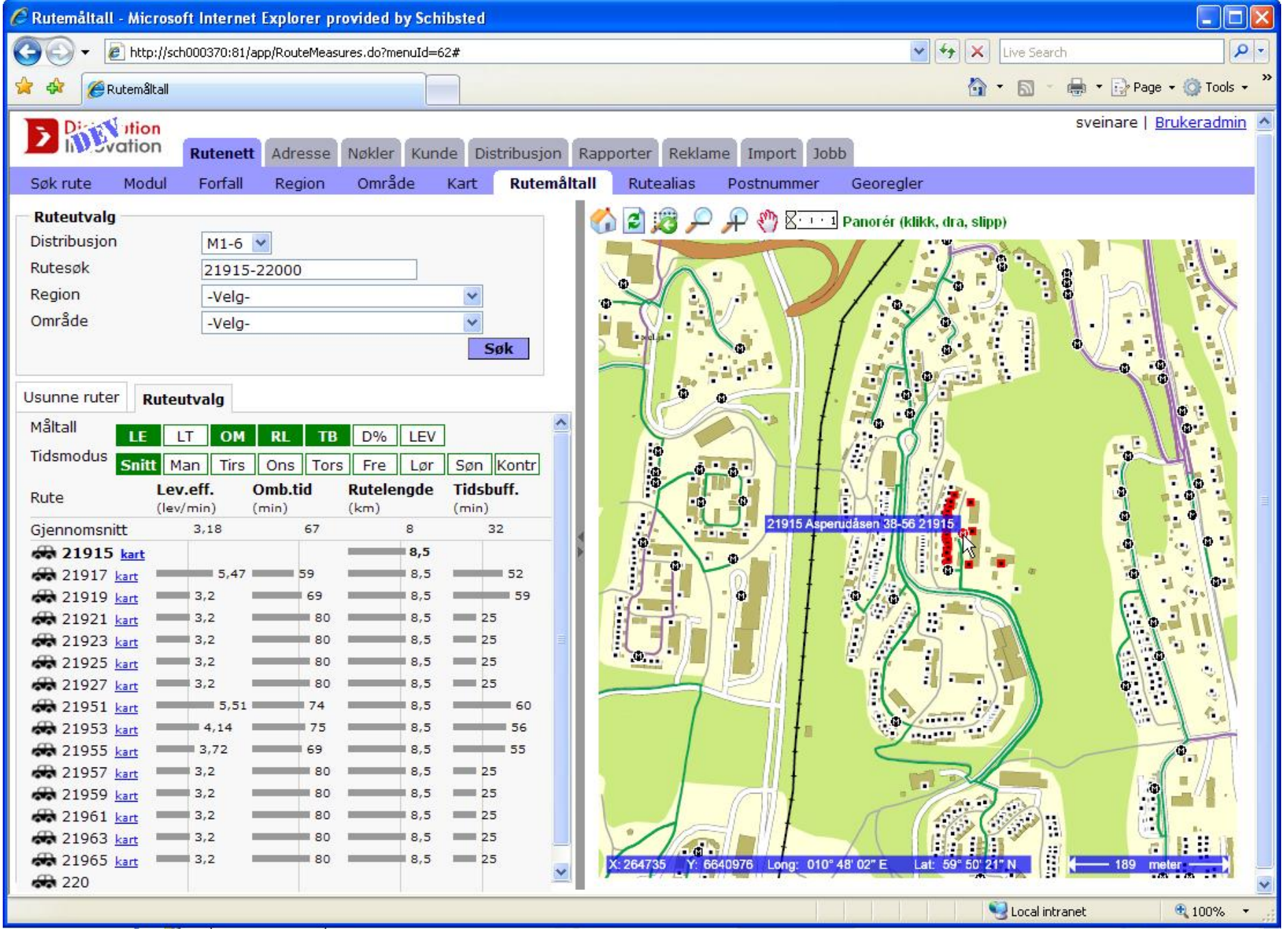


DOiT

- Dynamic and stochastic vehicle routing
- Uncertainty, mainly in travel time and load
- Inferring speed models from measurements
- Learning from historical data, Bayesian networks
- User Managed Innovation Project (2004–2007)
- Total budget ~16 MNOK, 1/3 RCN

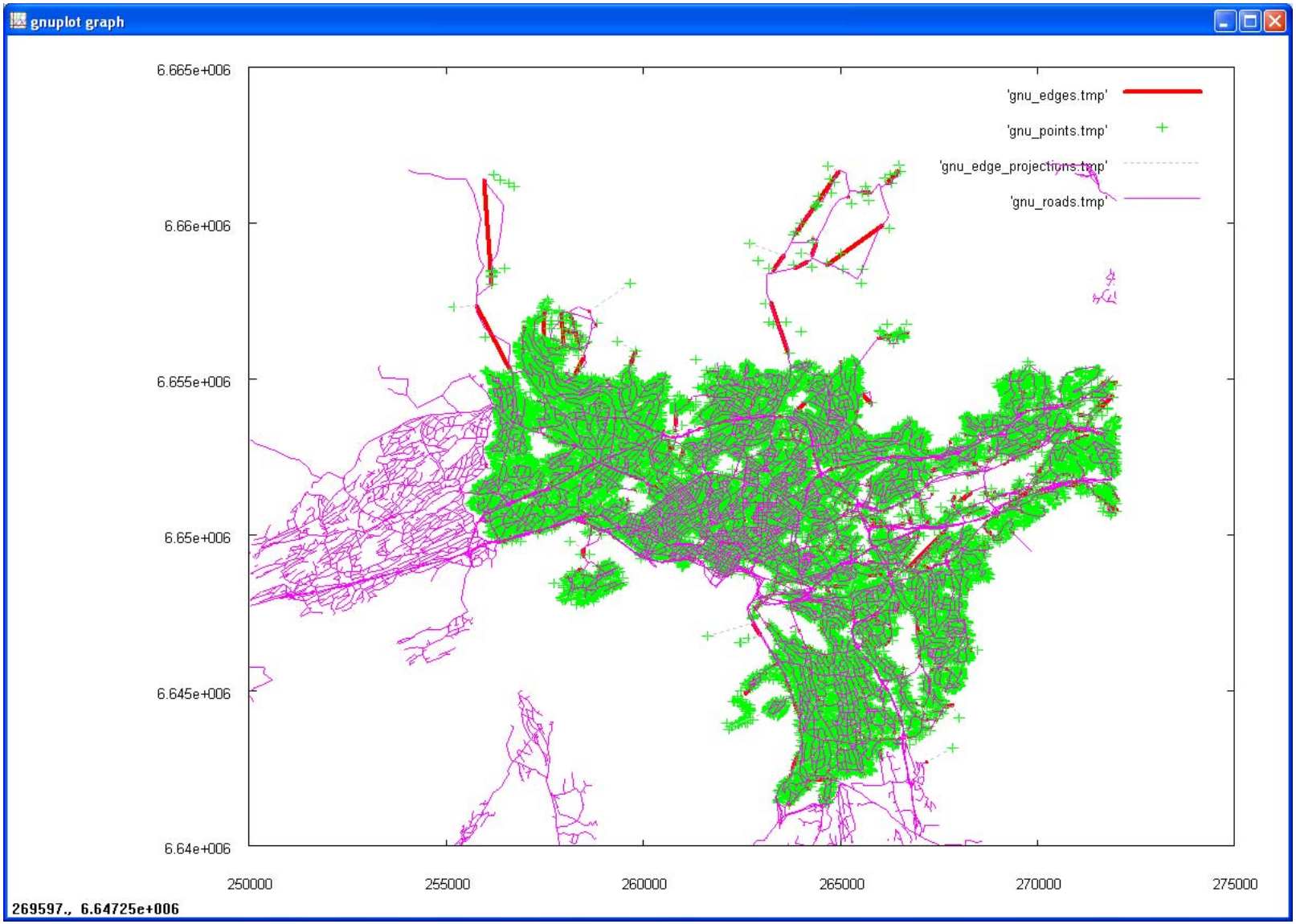
EDGE – Project 2005-2008




Rutemåltall - Microsoft Internet Explorer provided by Schibsted
http://sch000370:81/app/RouteMeasures.do?menuId=62#
Live Search
Rutemåltall
Page
Tools
sveinare | Brukeradmin
Rutenett
Adresse
Nøkler
Kunde
Distribusjon
Rapporter
Reklame
Import
Jobb
Søk rute
Modul
Forfall
Region
Område
Kart
Rutemåltall
Rutealias
Postnummer
Georegler
Ruteutvalg
Distribusjon
M1-6
Rutesøk
21915-22000
Region
-Velg-
Område
-Velg-
Søk
Usunne ruter
Ruteutvalg
Måltall
LE
LT
OM
RL
TB
D%
LEV
Tidsmodus
Snitt
Man
Tirs
Ons
Tors
Fre
Lør
Søn
Kontr
Rute
Lev.eff. (lev/min)
Omb.tid (min)
Rutelengde (km)
Tidsbuff. (min)
Gjennomsnitt 3,18 67 8 32
21915 kart 8,5
21917 kart 5,47 59 8,5 52
21919 kart 3,2 69 8,5 59
21921 kart 3,2 80 8,5 25
21923 kart 3,2 80 8,5 25
21925 kart 3,2 80 8,5 25
21927 kart 3,2 80 8,5 25
21951 kart 5,51 74 8,5 60
21953 kart 4,14 75 8,5 56
21955 kart 3,72 69 8,5 55
21957 kart 3,2 80 8,5 25
21959 kart 3,2 80 8,5 25
21961 kart 3,2 80 8,5 25
21963 kart 3,2 80 8,5 25
21965 kart 3,2 80 8,5 25
220
Panorér (klikk, dra, slipp)
21915 Asperudåsen 38-56 21915
X: 264735 Y: 6640976 Long: 010° 48' 02" E Lat: 59° 50' 21" N
189 meter
Local intranet
100%

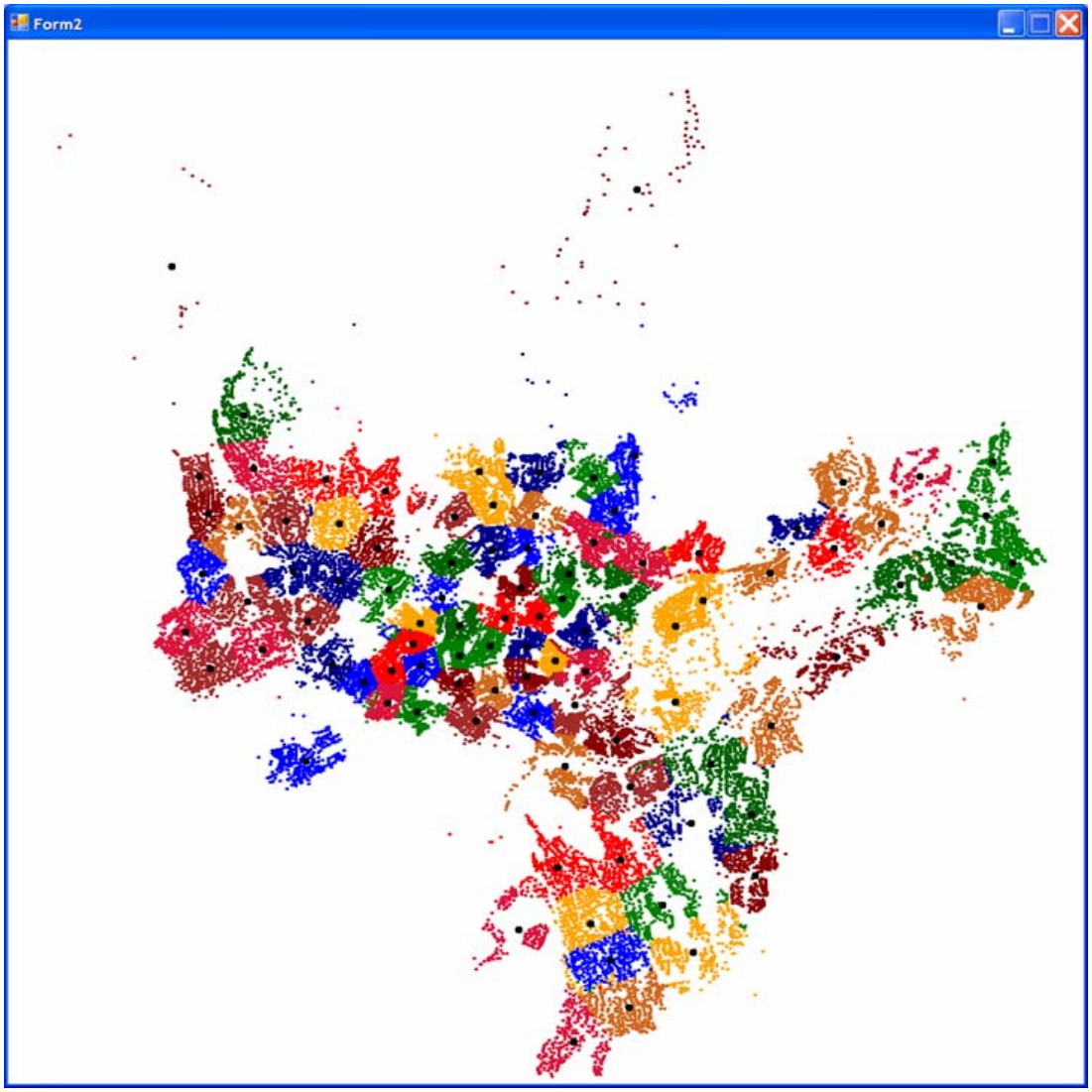
Case: Oslo data from Aftenposten

33.200 orders reduced to 5600 aggregates




gnuplot graph
'gnu_edges.tmp'
'gnu_points.tmp'
'gnu_edge_projections.tmp'
'gnu_roads.tmp'
6.6514e+006
6.6512e+006
6.651e+006
6.6508e+006
6.6506e+006
6.6504e+006
6.6502e+006
6.65e+006
6.6498e+006
262400
262600
262800
263000
263200
263400
263600
263800
264000
263275., 6.65038e+006

35.000 orders – Aftenposten in Oslo
Decomposition into some 100 sub-areas



Effekt (2008-2011)

- follow-up of EDGE, distribution part
- Distribution Innovation AS
- Aftenposten Distribusjon AS
- RMD AS
- Edda Media AS
- Norkart AS

- Agora Innoroad Laboratory, Univ. Jyväskylä
- SINTEF ICT

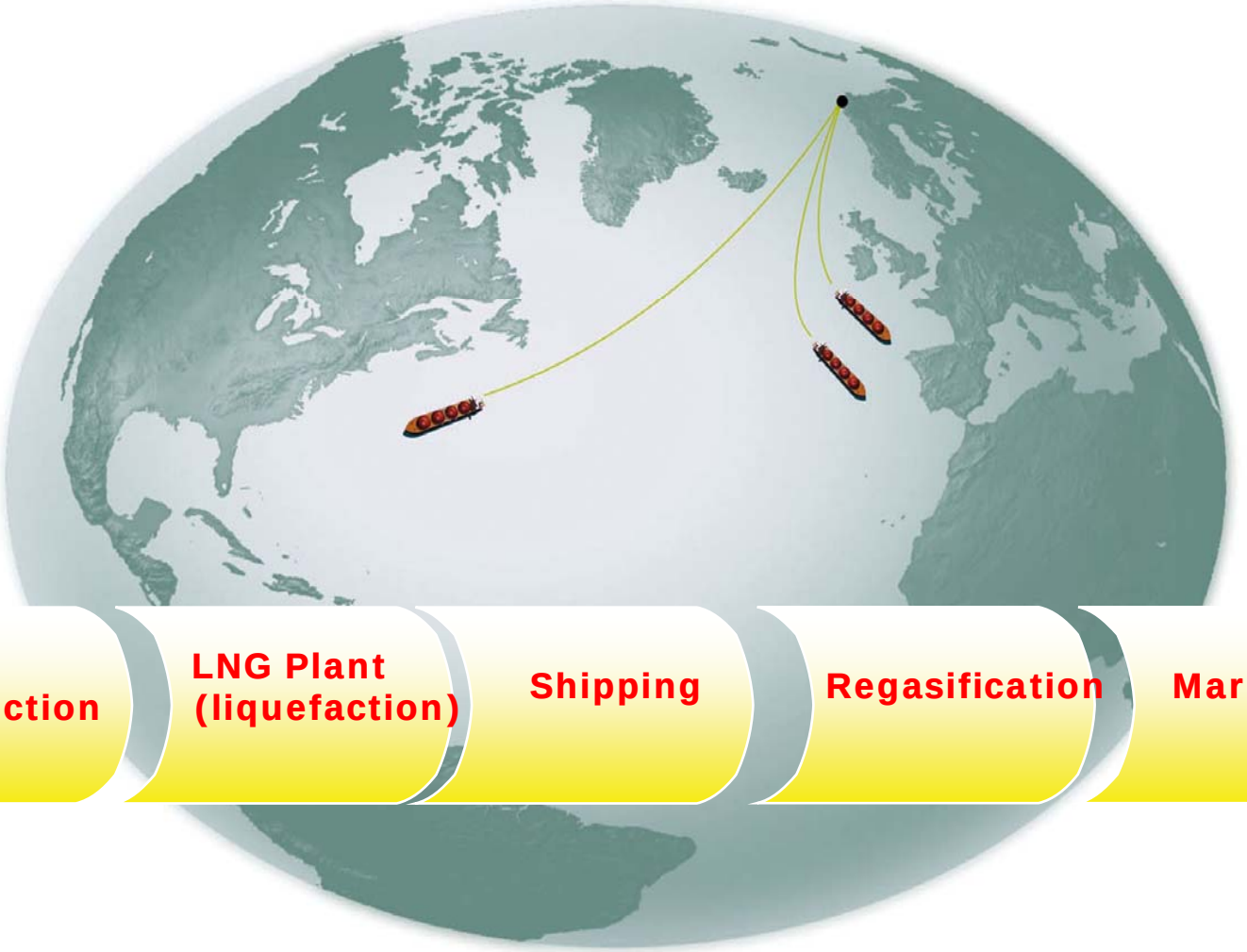
Maritime transportation and logistics

- SINTEF-funded strategic project (11 MNOK, 2005-2008)
- MARINTEK, SINTEF T&S, SINTEF ICT, NTNU
- Large, internationally well reputed group
- Generic maritime inventory routing
- Liquefied Natural Gas value chain
- Optimized liner shipping
- 33 MNOK projects portfolio
  - Broström Tankers (soon to be Maersk)
  - StatoilHydro
  - Gas de France / Suez Energy
  - DnVeritas
  - Saga Forest Carriers
  - Höegh Autoliners
  - partly funded by RCN

Invent – SINTEF ICT

- Generic sw library to solve Inventory Routing Problems
  - Primary focus on routing and inventories
  - Extended with bookings and contracts
- Three applications used as pilot studies
  - Cement - multiple products, short horizon, no spot
  - Chemical tankers - tramp and inventory, multiple products, tank handling, cleaning
  - LNG - single product, long term, contracts, full load

LNG value chain



Gas production → LNG Plant (liquefaction) → Shipping → Regasification → Marketing

Production port

Consumption port

Product 1

Product 2

Alta

Kjøpsvik

Mo i Rana

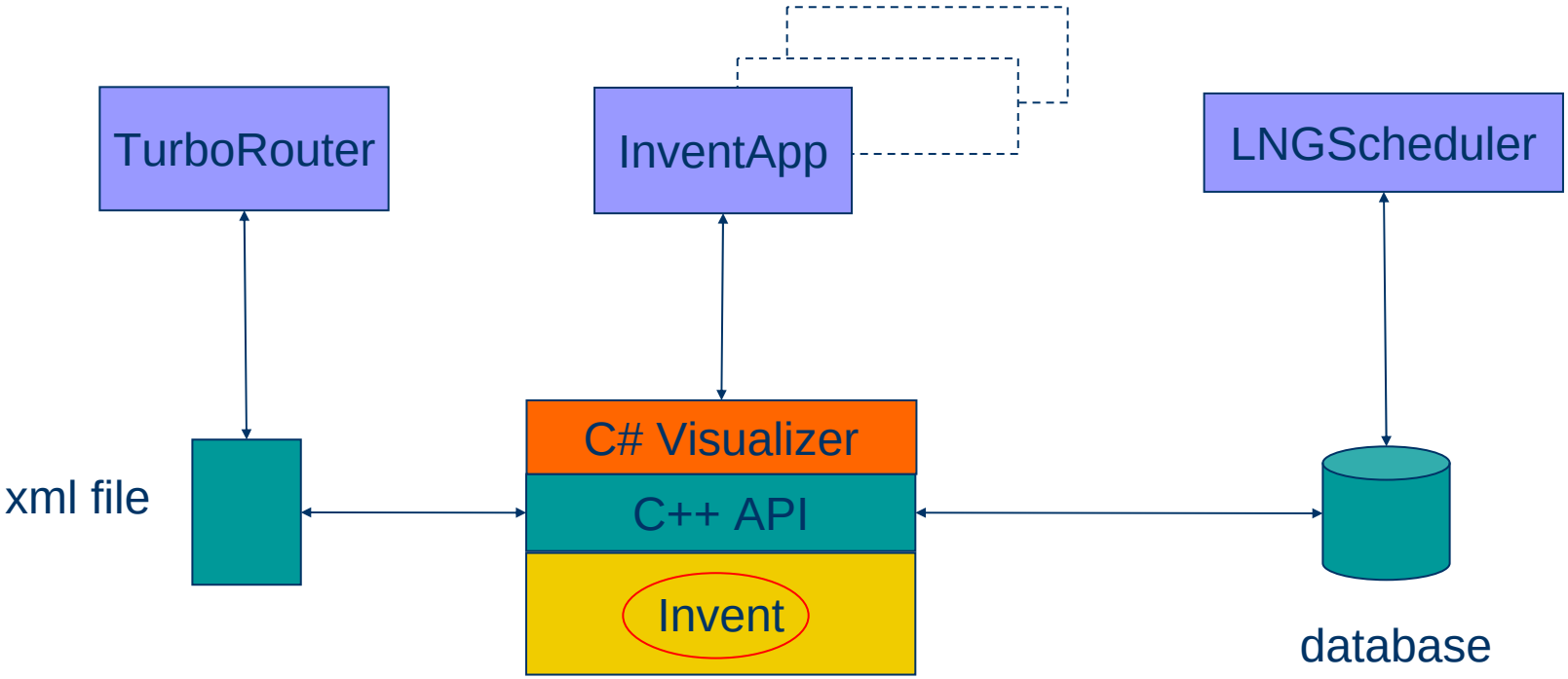
Trondheim

Karmøy

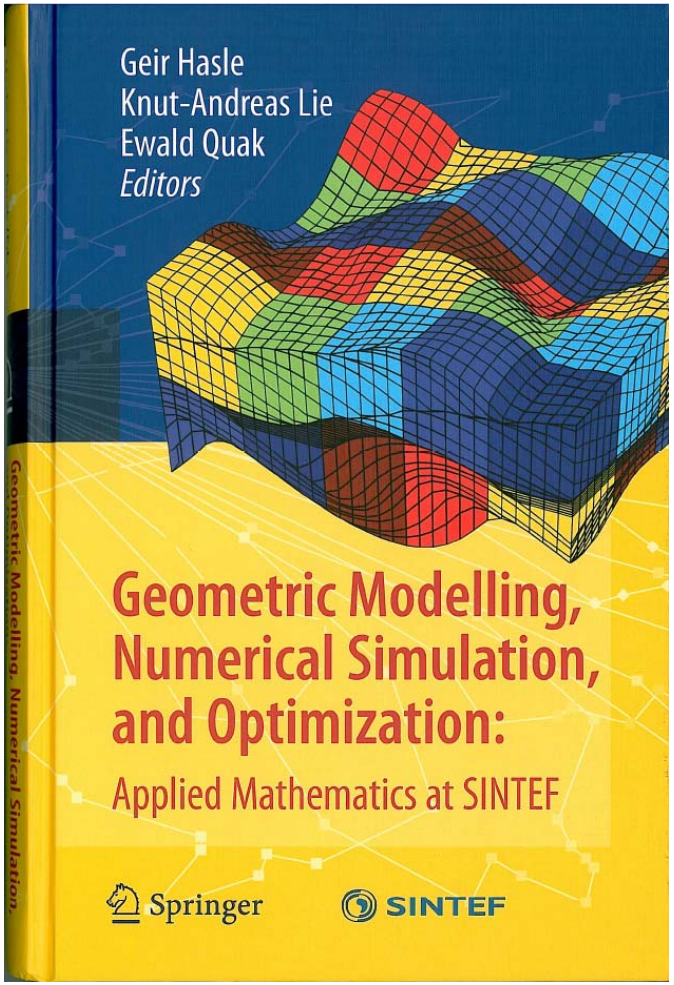
Årdal, Rogaland!

Brevik

Invent - integration



Hasle, Geir; Lie, Knut-Andreas; Quak, Ewald (Eds.)
Geometric Modelling, Numerical Simulation, and Optimization: Applied Mathematics at SINTEF
2007, XI, 558 p. 162 illus., 59 in color., Hardcover. ISBN: 978-3-540-68782-5
http://www.springer.com/



Applied Optimization at SINTEF

Chief Scientist, Dr. scient. Geir Hasle
SINTEF ICT, Oslo, Norway

Invited talk

University of Jyväskylä

October 9 2008