Lubricants in Industry 4.0

International Conference on Sustainable Manufacturing

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LUBRICANTS. TECHNOLOGY. PEOPLE. FUCHS

Agenda

01 **Our company at a glance**
facts and figures

02 **Digitization in the lubricants industry**
simulation / calculation / sensor technology / big data

03 **Lubricant applications in Industry 4.0**
internal fluid control / chemical-mechanical interaction

04 **Limitations**
sensor technology / economics / access to data

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FUCHS Lubricants is your smart technology partner

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Established 3 generations ago as a family-owned business

No. 1 among independent suppliers of lubricants

Fuchs family holds 54% of ordinary shares

More than 2.3 bn euro sales in 2016

57 companies worldwide

A full range of over 10,000 lubricants and related specialties

Almost 5,000 employees

Technology and Innovation market leader in strategic product lines

Present on all continents with 24 laboratories

447 employees working in R&D

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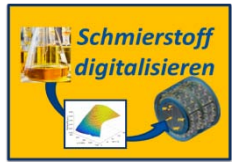
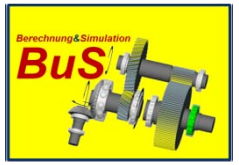
Digitalization is shortening the development cycle

- Increase of efficiency and accuracy by introducing automation
- Speed up during the development and shorten the time to market
- Reducing the number of trials
- Developing test methods for screening during the development phase with a high level of predictability
- Challenge: parametrisation of the lubricant and its properties to fit into the calculation models

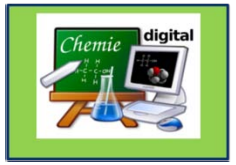
Digital Methods are making chemistry smarter



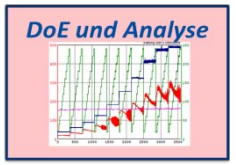
- Development of methods to describe the lubricant correctly in tribological sense for further application in simulations and calculation



- Simulations and calculation to support and speed up R&D works



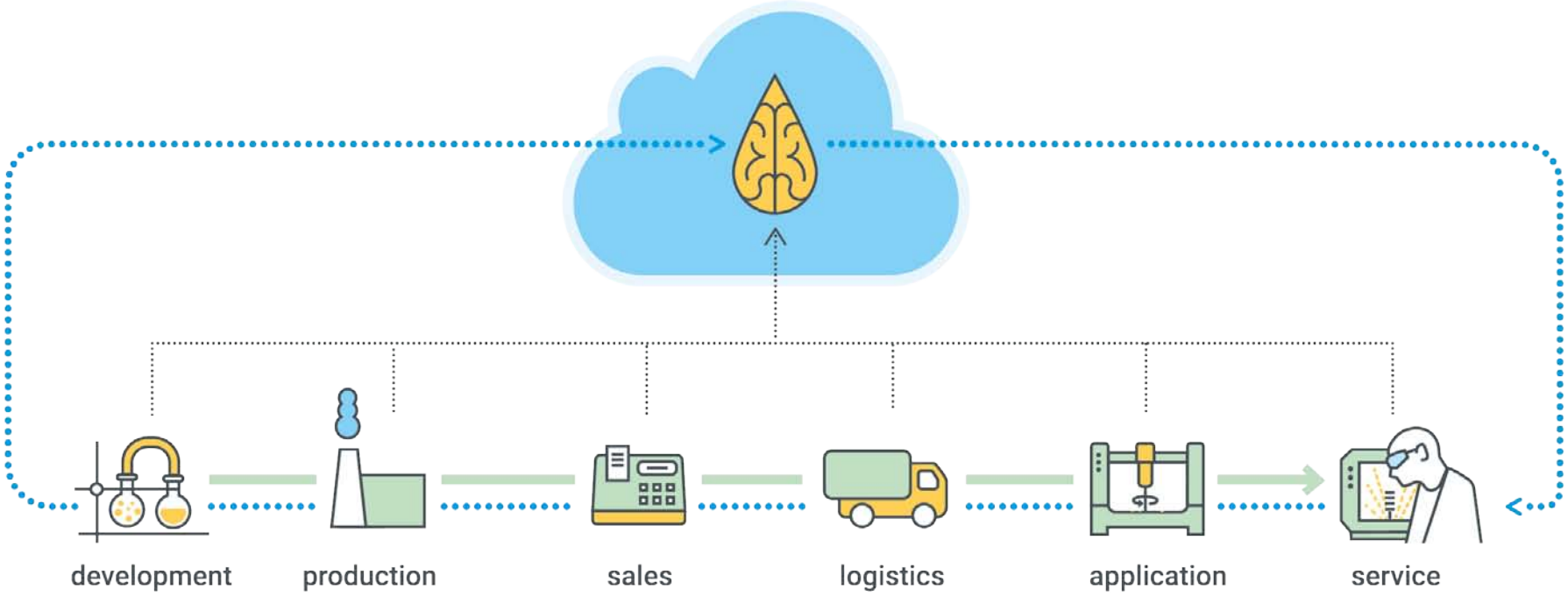
- Calculation of molecules and their in between interaction and with the surfaces.



- Design of Experiments: Support of R&D to analyze complex tests, establishing of new technics of panning of experiments and their evaluation

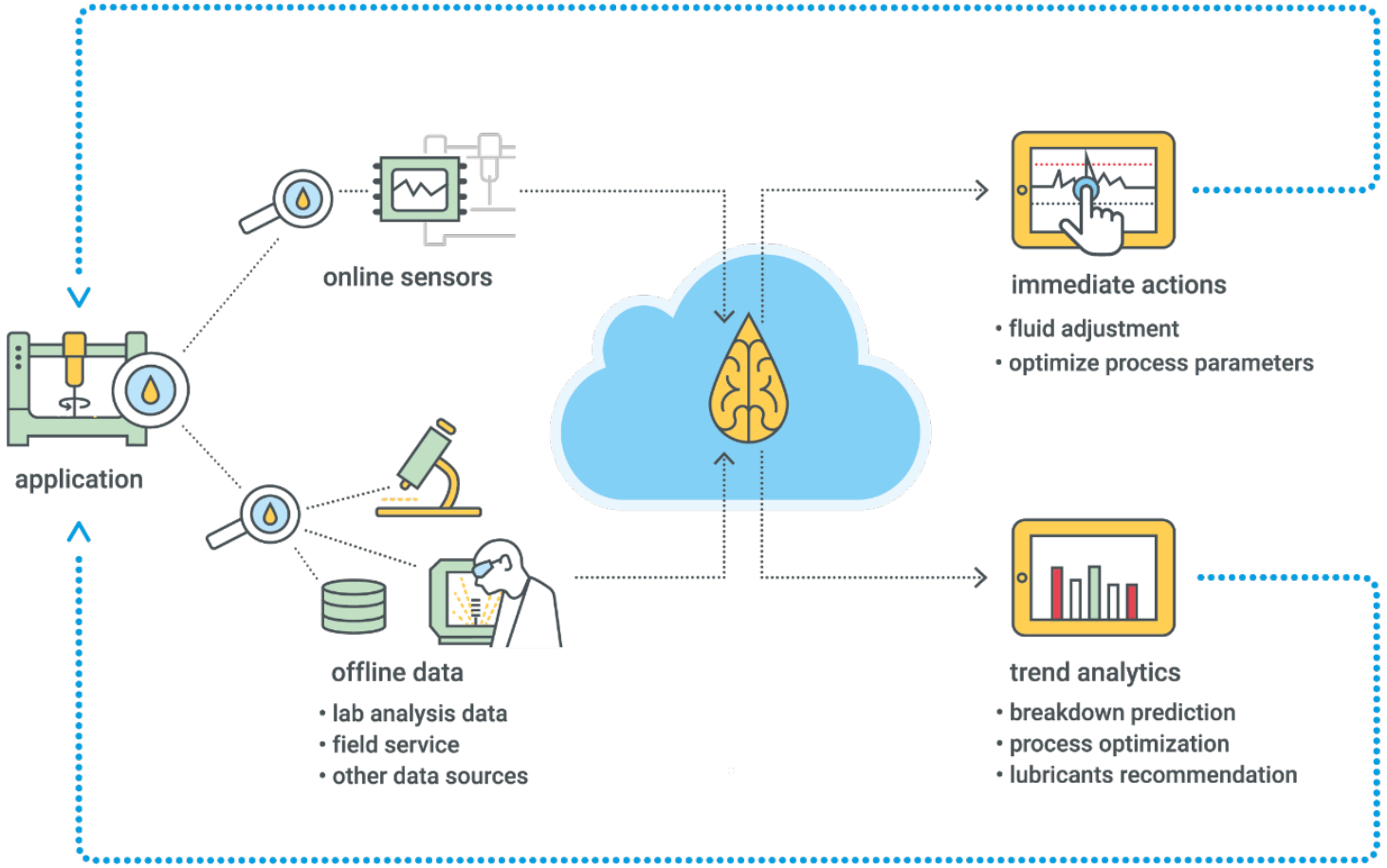
- Sensor technology: „smart lubricant“

Digitalization will fundamentally change value creation



- Data collection throughout the whole value-chain will be widened compared to todays standards
- Direct and automated usage of information generated at a later step of the process will affect all steps before
- An extended exchange in between you and your lubricants company will allow for new services and therewith add extra value to your business

The data ecosystem governs tactical & strategic decisions



- Introducing online-monitoring for lubricants in addition to offline-analyses
- Combine lubricants data with machine data (e.g. vibration or load) to generate a more holistic view
- Provide a basis for decisions on immediate actions to keep the fluid healthy
- Support the local fluid management

Monitoring application and creating data driven services

1 Traditional data sources

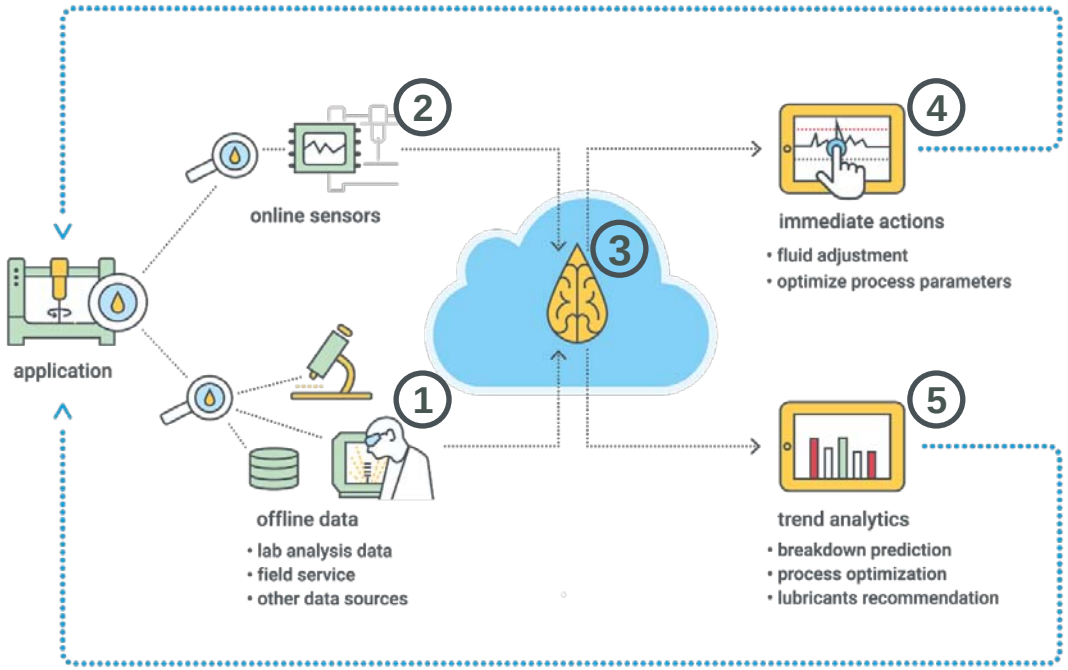
- Nominal values as determined in the new lubricant
- Historical data
- R&D data
- Lab analysis data
- Field service data
- Machine data

2 Online sensors

- Realtime measurement of key parameters
- Continuous determination of relative changes

3 Central data base and data analytics

- All data collected from traditional data sources and online sensors
- All data converted into a single format
- Data analysis and visualisation
- Realtime evaluation of measured parameters as basis for decision-making



4 Immediate actions

- (Automated) fluid adjustments
- Optimization of process parameters
- Preservation of process stability
- Avoidance of process break downs
- Prevention of health hazards

5 Trend analytics

- Comparison of current data with historical data to predict the remaining useful life
- Supports predictive maintenance approaches
- Identification of complex corelations

Traditional data will be augmented by field data

- **Laboratory**

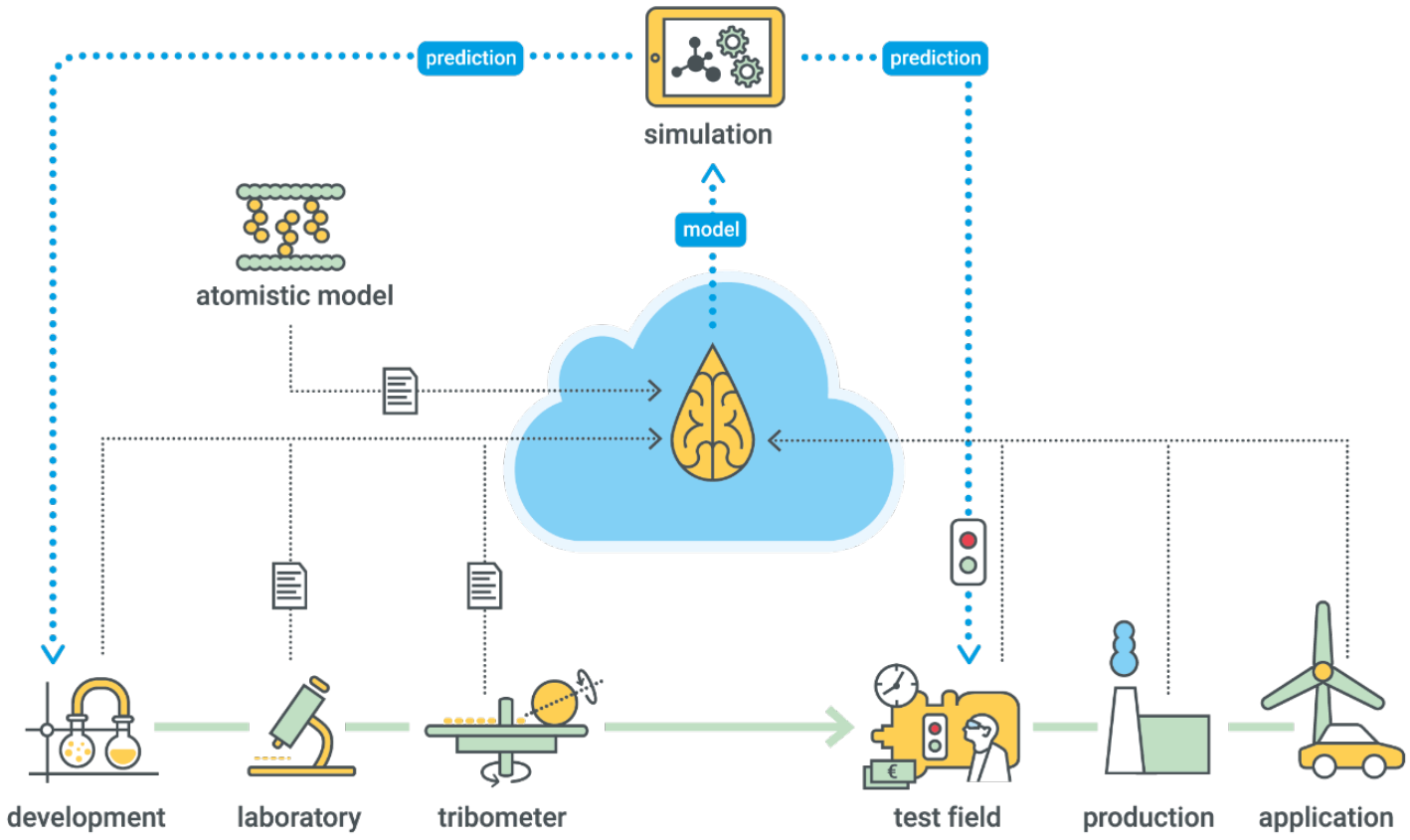
Viscosity, acid number, water content, purity, wear elements, IR spektrum (oxidation, losses of additives) ...

According to DIN, ASTM, ISO etc.

- **Sensors**

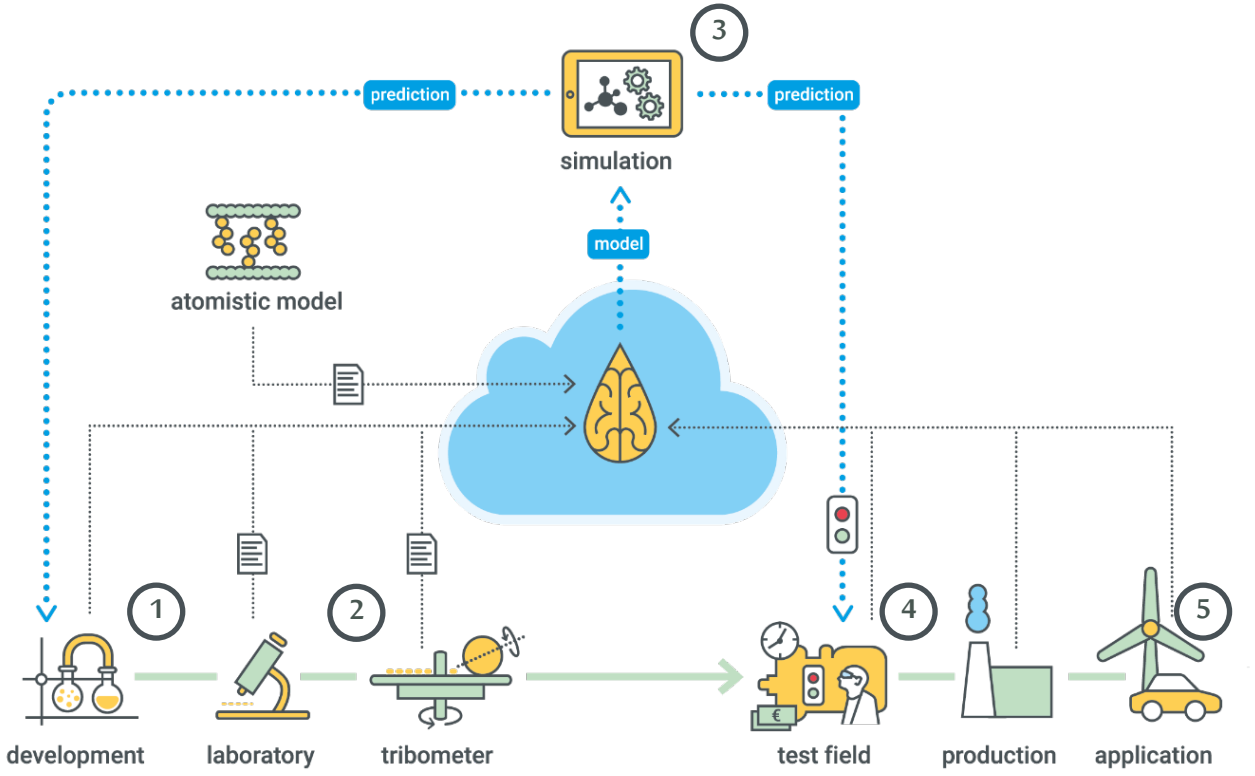
Dielectric constant
Refractive Index
tan δ
PQ-Index
Viscosity
oil condition
Contaminants
Air entrainment
oil quality
microbial
Moisture
pH
Particles

Using digitized tools to support lubricant development



- Transform product development from being empirically-driven to using data and simulation approaches!
- In doing so, application related information such as field data or test field results serve as a statistical backbone.
- A more focused development will be granted by implementing the later application into product development by introducing simulation approaches into R&D.

Using digitized tools to support lubricant development



1 lubricant development

- application-oriented design
- today: mostly characterized by know-how & empiricism

2 laboratory & tribometer

identification of relevant lubricant's properties (simplified test rigs)

- chemical & physical
- friction & flow behaviour

3 simulation

- chemical & mechanical modeling of tribological problems
- prediction of tribological behavior with regard to chemical composition, operating conditions as well as interdependencies
- identification of product requirements
- gathering and process relevant data
- optimized work-flow to develop effective product

4 test field

- qualification test with operating conditions close to real application
- costly in terms of time and labor
- benefit from preselection with digital methods

5 application

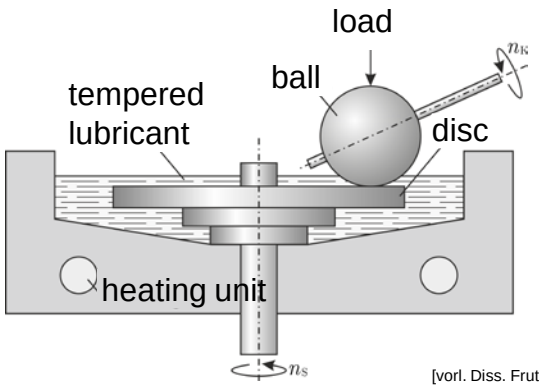
- succesfull product due to dedicated lubricant design
- experience in the field as input for Big Data

Using digitized tools to support lubricant development

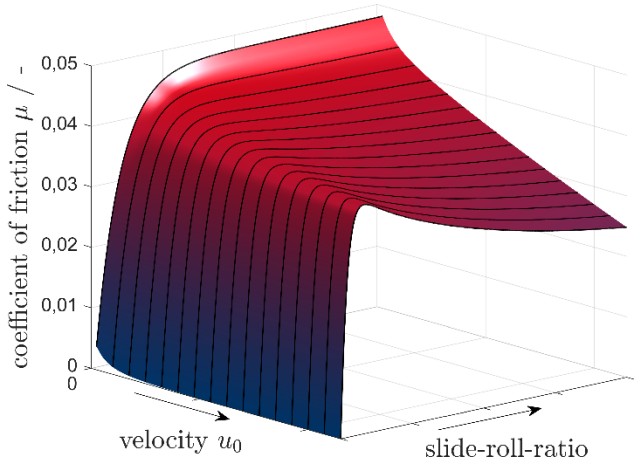
deduction of relevant frictional behaviour

tribometer test rig: friction mapping

i.e. ball-on-disk (MTM)

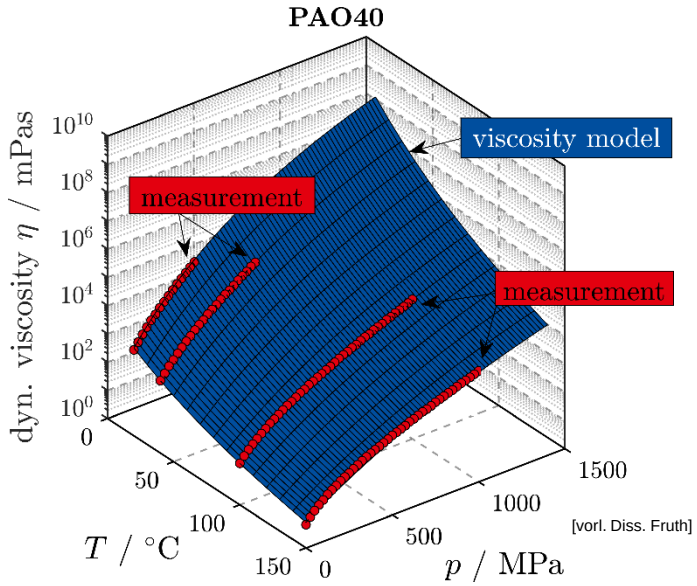


[vorl. Diss. Fruth]



high pressure viscosimetry

i.e. quartz viscosimeter



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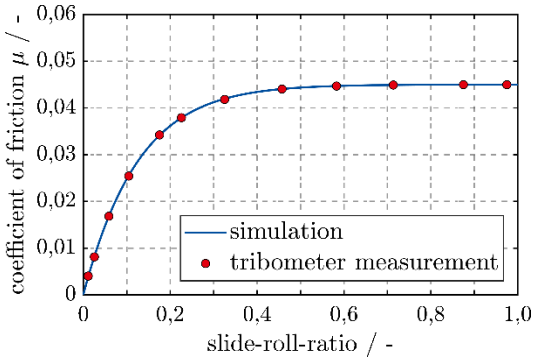
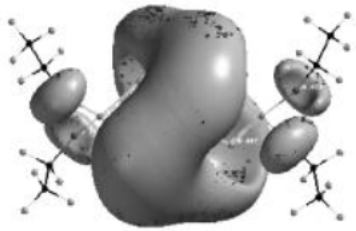
fluid model / shear behaviour

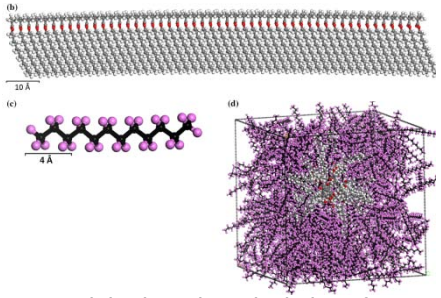


Current atomistic simulations

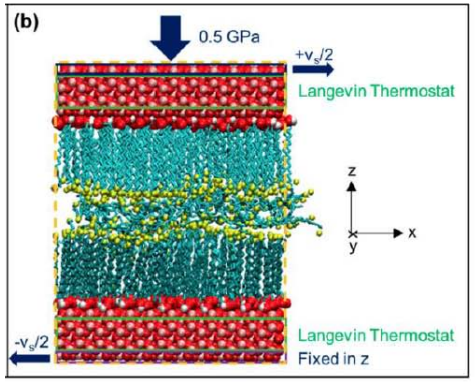
- Calculation of polarity and reactivity of molecules in the gas phase
- Calculation of the viscosity of base oils / VII
- Calculation of the viscosity of base oils
- Calculation of the friction of base oil / friction modifier
- Reaction of additivies on metal surfaces
- Methods: quantum mechanics
  molecular mechanics
  molecular dynamics



P. Nair: Orbital structure and reactivity of ZnDDP (2006)



A.Martini: Viscosity calculation of PAMA / dodecane (2016)



D.Dini: Calculation of the friction coefficient of stearic acid / hexadecane on Fe surfaces (2016)

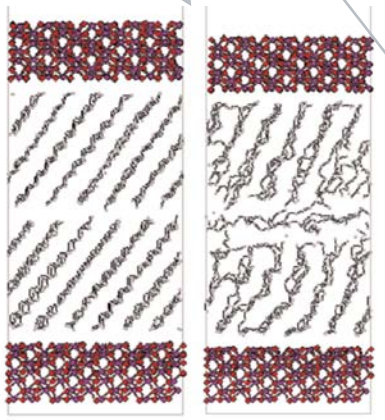
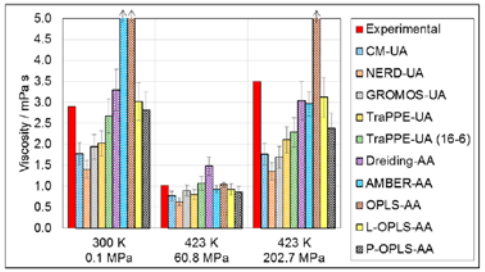


Fig. 7. Organization of the film during friction process-snapshot after 1 ns of MD simulation: (a) stearic acid 15 molecules per layer, (b) linoleic acid 15 molecules per layer, (c) stearic acid 24 molecules per layer, (d) linoleic acid 24 molecules per layer.

JM Martin: Simulation of the reaction of fatty acids on Fe, FE_2O_3 surfaces by chemisorption (2016)



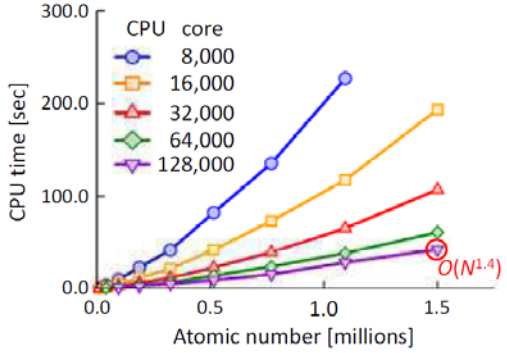
D.Dini: Calculation of the viscosity of hexadecane (2016)

Current atomistic simulations

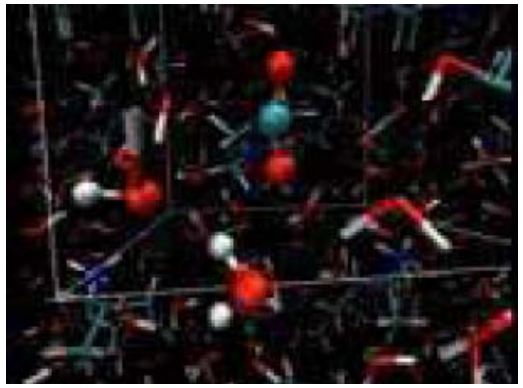
- Many tribological questions can be answered today with computational chemistry methods:
  - Stability of additives
  - Reaction on surfaces
  - Viscosity
  - Density
  - etc.
- However, the computational capabilities still limited and not suited to compute complex oils, big cells and long time axis
- Future trends will implement faster algorithms for quantum mechanical calculation and molecular dynamics
- Further improvements in the computer hardware are expected in the near future.

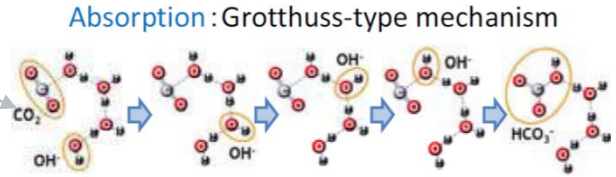
Future Trend: Improved algorithms

- Chemical reactions are characterized by the change in the electronical structure
- It is mathematically described by the Schrödinger equation
- In 1980 the DFT improves the quantum mechanical calculation by magnitudes and reduces the computational time tremendously
- These algorithms are further developed
- In 2016, e.g. the DC-DFTB was developed (linear-scaling divide-and-conquer technique with the density functional based tight binding
- This approach is suitable for massive parallelized computers (e.g. 128 000 cores)
- Millions of atoms and complex reactions with many different molecules can be computed simultaneously with DC-DFTB



H Nakai: DC-DFTB calculation of proton transfer in thousands of water molecules (2016)





H Nakai: Reaction mechanism of CO_2 adsorption in homegenous catysed reaction (2016) in the presents of Amines, H_2O OH^-, H_3O^+

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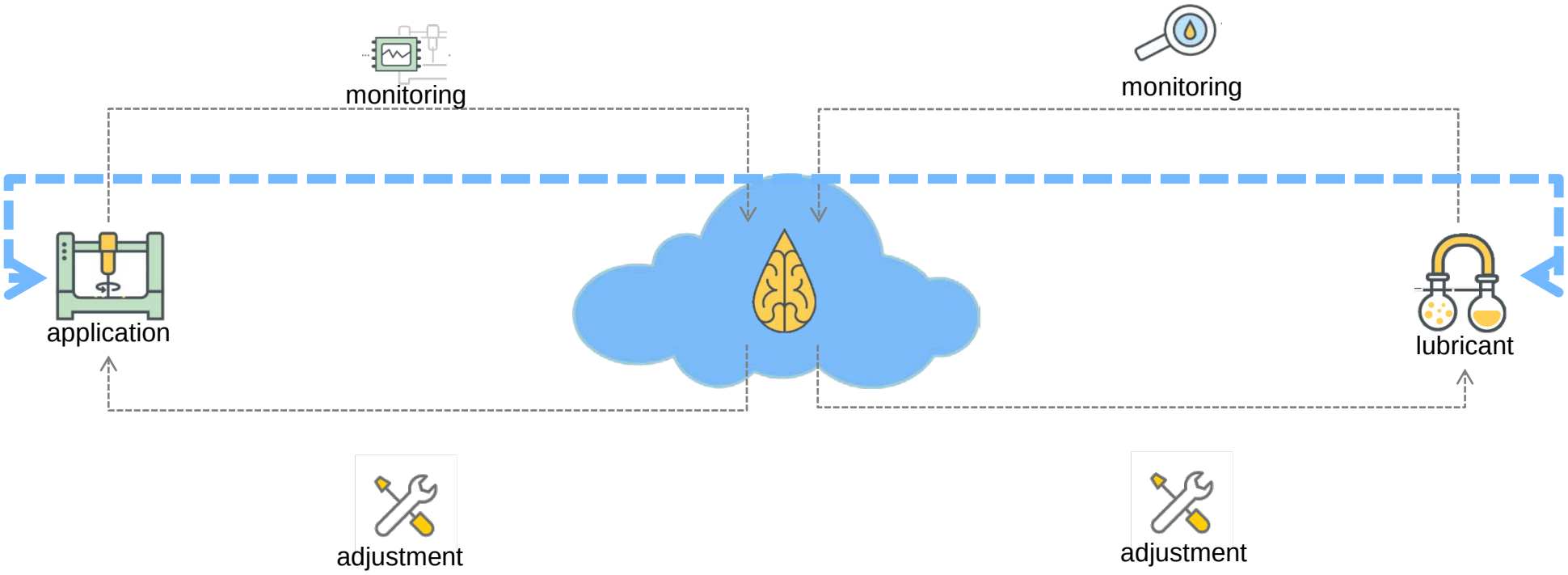
Manufacturing process can be optimized by simultaneously adjusting application and fluid parameters



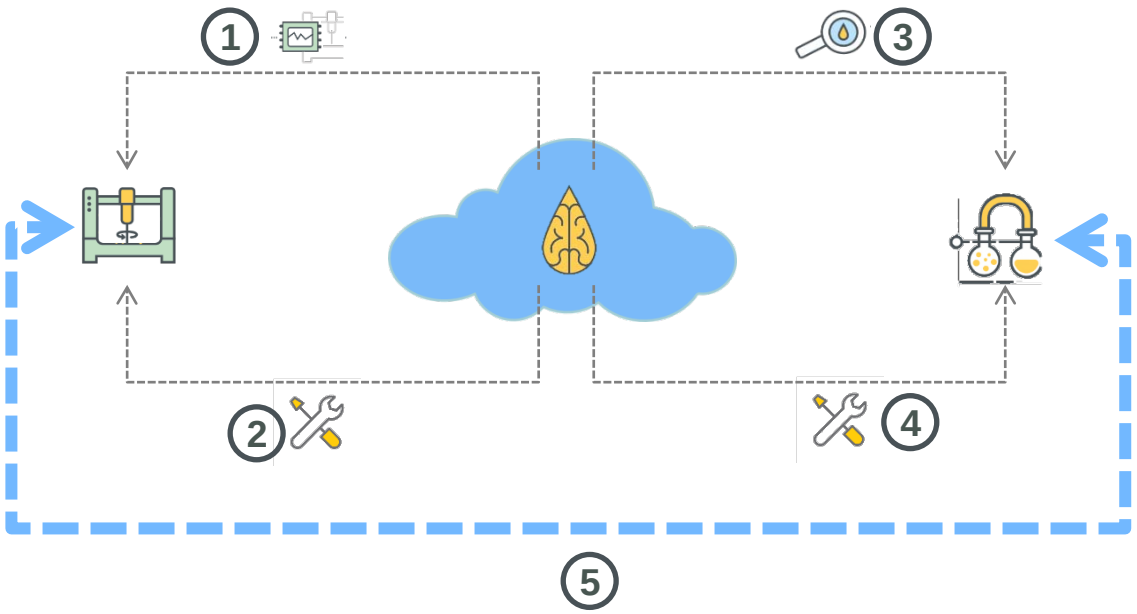
Manufacturing process can be optimized by simultaneously adjusting application and fluid parameters

1 Application monitoring

- Tooling
- Machine
- Material
- Environment
- Quality control data

2 Application correction

- Feed rate
- Cutting speed
- Tool change
- Workholding pressure
- Fluid delivery pressure



3 Fluid monitoring

- Concentration
- Microbial growth
- Tramp oil content
- Corrosion protection
- Lubricity
- Foaming
- Detergency

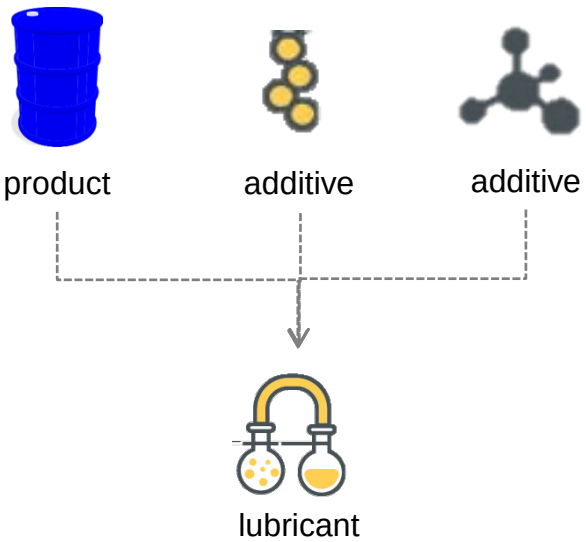
5 Fluid correction

- Concentration
- Biocides
- pH boosters
- Corrosion addtives
- Antifoam
- Emulsifiers
- Lubricants
- Turn on skimmers

5 Application – fluid interaction

- Adjust machining parameters to fluid condition (i.e. Age)
- Adjust fluid parameters to application capability

Smart control of application & fluid parameters ensure process optimization



1 Application parameters

- Cutting speed
- Feed rage
- Metal removal rate
- Tool life

3 Lubricant parameters

- Concentration
- Lubricity
- Wetting
- Detergency
- Corrosion protection

2 Material parameters

- Hardness
- Alloy composition
- Microstructure
- Environment
- Downstream processes
- Storage time

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Limitations to achieving Industry 4.0 with lubricants

- Variety of sensor technology to measure relevant lubricant parameters

- Robustness & reliability of sensors in real world environment

- Economical cost structure

- Lubricants designed to be measured

- Access to data

Thank you for your attention.

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