UNIVERSITÄT ZU LÜBECK

Information Systems

CS4130-KP06

Prof. Dr. Sylvia Melzer

SoSe2026

Research Software Engineering

Information Systems

What You Will Learn

- Understand principles of Software Engineering (SE)
- Explain Research Software Engineering (RSE)
- Distinguish SE, RSE, and interdisciplinary RSE
- Describe interdisciplinary RSE workflows
- Understand why sustainable software development matters in research
- Explain why interdisciplinary communication is central in RSE

Why Software Engineering (SE)?

- Writing a **small program** is usually manageable for **one person**
- **Problems** arise when software becomes **larger and more complex**
- **Large systems** involve **many developers, users, and components**
- Different parts of the system must **work together** reliably
- Even **small changes** can create **unexpected errors** elsewhere
- Software must often run for **many years** and continuously evolve

Example:

Development of small system

- One person
- Short-lived
- Local files
- Simple debugging

Development of large system

- Many teams
- Long-lived
- Distributed data
- Coordination overhead

System Development: Small vs. Large

- In small systems, complexity is still visible and understandable to one person
- In large systems, complexity becomes distributed across many people, components, and workflows
- Large software is not only “more code”
- It is mainly:
  - more dependencies
  - more coordination
  - more communication
  - more long-term maintenance

Goals of Software Development

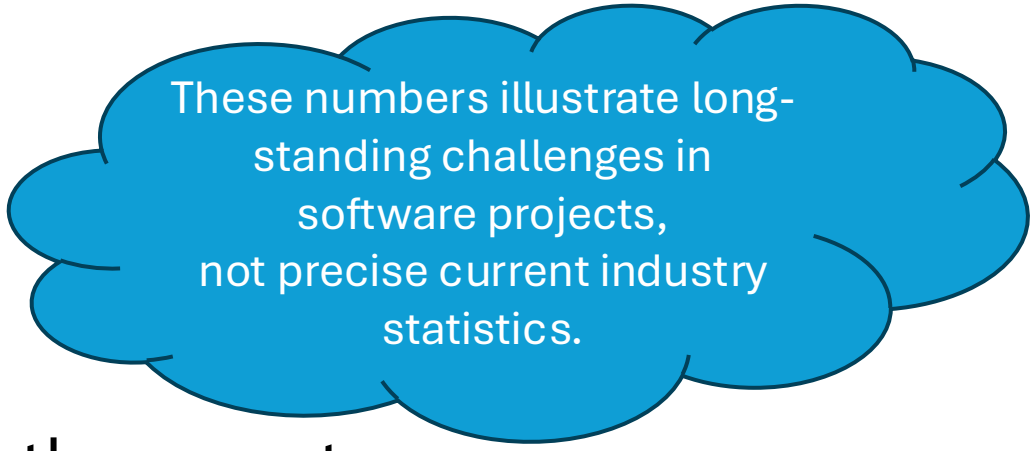
Software engineering tries to balance several important goals:

- Software **should satisfy users requirements**
- Systems should be **reliable** and work correctly over time
- **Maintenance** and future changes should remain **manageable**
- Projects should be completed **within deadlines**
- Development **costs should stay reasonable**
- Software should **perform efficiently** and **respond quickly**
- Components should be **reusable** in future projects

https://www.cs.ox.ac.uk/people/michael.wooldridge/teaching/soft-eng/lect01.pdf

Satisfying User Requirements

- Many programs simply don't do what end users want
- Typical percentages for large-scale commissioned systems:
  - 45% delivered but not used
  - 27% paid for but not delivered
  - 17% abandoned
  - 6% used after changes
  - 5% used as delivered
- Users find it hard to articulate what they want
- Developers find it hard to understand what users say!



https://www.cs.ox.ac.uk/people/michael.wooldridge/teaching/soft-eng/lect01.pdf

Two Incompatible Ways of Knowing

Humanities Logic

Dimension 1: The Role of Context

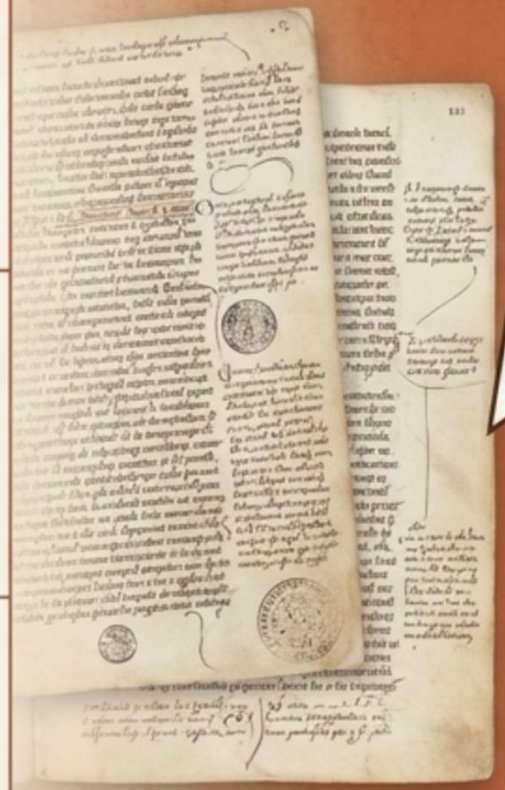
Meaning is entirely dependent on context, layered reception, and symbolic weight.

Dimension 2: The Treatment of Ambiguity

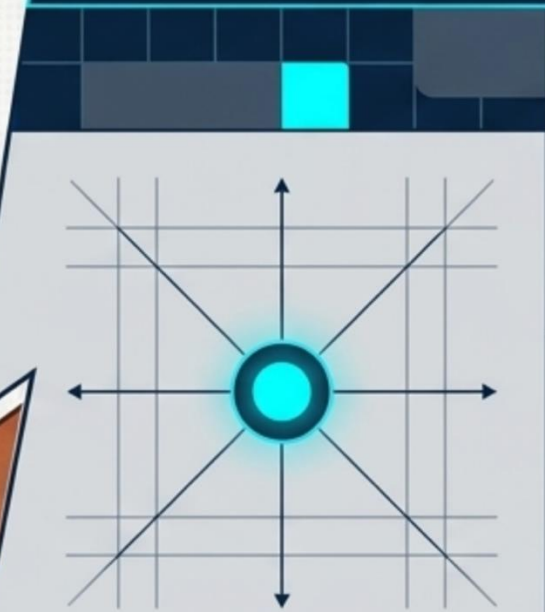
Ambiguity is constitutive and intentional (e.g., contested attributions).

Dimension 3: Data Representation

Continuous prose, marginalia, and overlapping structural boundaries.



Computational Logic



Dimension 1: The Role of Context

Meaning must be atomized, strictly categorized, and isolated from external ambiguity.

Dimension 2: The Treatment of Ambiguity

Ambiguity is an error. Data must be forced into `First Normal Form (1NF)`.

Dimension 3: Data Representation

Discrete fields, binary relationships, and rigid hierarchical schemas.

NotebookLM

High Reliability

Errors in software are commonly called bugs
Bugs can never be completely ruled out
Testing can reveal existing problems
However, proving that no bugs exist is extremely difficult
Reliable software is essential in critical systems
Failures can have serious real-world consequences
Software quality directly affects trust and safety
In research contexts, reliability also affects reproducibility, transparency, and long-term usability of scholarly data

https://www.cs.ox.ac.uk/people/michael.wooldridge/teaching/soft-eng/lect01.pdf

Consequences of Software Failures

- Human Safety
  - Aircraft systems
  - Medical systems
  - Nuclear power systems
- Financial Damage
  - Failed software projects
  - System outages
  - Expensive launch failures
- Reputation Damage
  - Loss of customer trust
  - Negative public perception
  - Long-term business consequences

Consequences of Software Failures in the Humanities

- Research data may become inaccessible or lost
- Digital editions and annotations can become corrupted
- Incorrect analyses may lead to false interpretations
- Poor metadata can make research data difficult to find or reuse
- Broken infrastructures interrupt research workflows
- Researchers can lose trust in digital methods and infrastructures

Maintenance Costs

Software continues evolving after release

Most project costs occur after deployment

Maintenance is often more expensive than initial development

Small changes can unexpectedly affect other components

Understanding existing systems is often difficult

Poor documentation increases maintenance effort

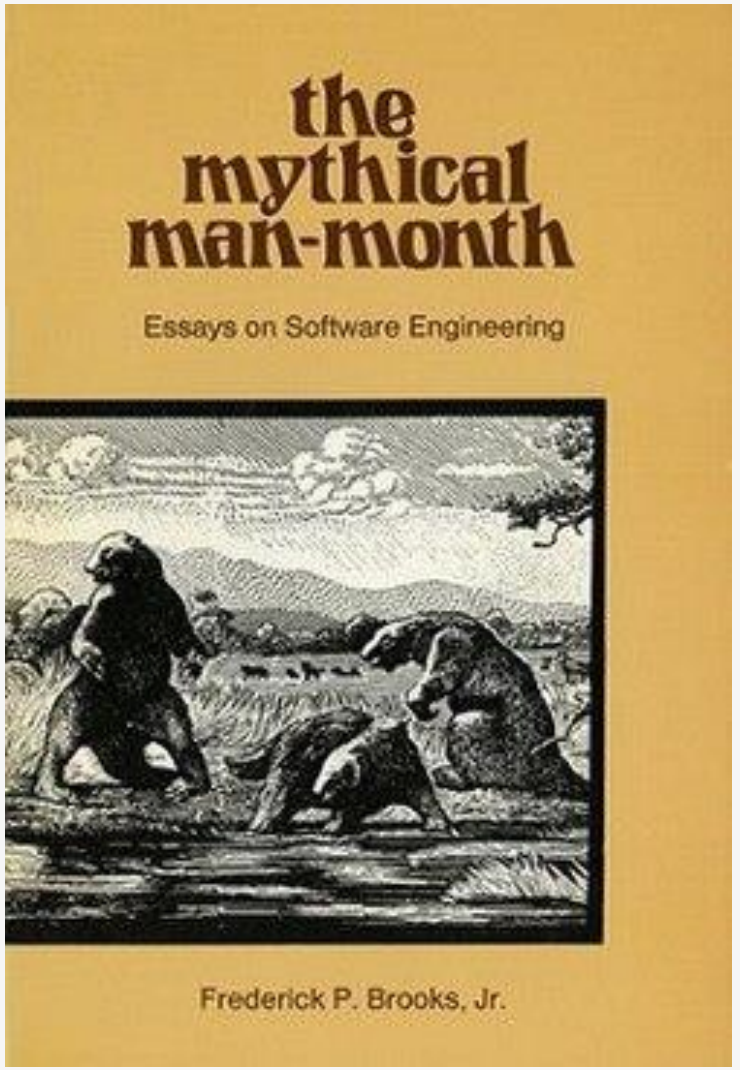
Sustainable software requires maintainable design

- Corrective: Fixing bugs
- Adaptive: Adjusting to new environments
- Perfective: Adding new features and requirements
- Preventative: Improving long-term maintainability
- **Most software engineering work is not writing new code, but understanding and adapting existing systems**

Delivery on Time

Brooks' Law:
"Adding manpower to a late software project makes it later."

- Software projects are notorious for overrunning
- It is extraordinarily hard to reliably predict how much effort a software project will require, and when it will be completed
- The relationship between person months devoted and development time is almost never linear:
  - adding person months of effort to a project frequently has no effect;
  - adding person months of effort often makes the project slower



https://www.cs.ox.ac.uk/people/michael.wooldridge/teaching/soft-eng/lect01.pdf, https://en.wikipedia.org/wiki/The_Mythical_Man-Month

Production Costs

Software production is an enormous industry:

- **The global custom software development** market size is anticipated to grow from $53.02 billion in 2025 to $334.49 billion by 2034, at a CAGR of 22.71%. Enterprise software accounted for 61% of the market, with large enterprises holding the largest revenue share of over 61%
- The **global software market** size was $823.92 billion in 2025 and is expected to reach around $2,248.33 billion by 2034, expanding at a CAGR of 11.8% from 2025 to 2034
- The software testing segment within the **software engineering** market is expected to hold a share of over 38% by 2032
- **Software market growth** around 10–12% annually
- Software engineering is not only a technical activity, but also a major economic and organizational factor

https://www.itransition.com/software-development/statistics; https://www.cs.ox.ac.uk/people/michael.wooldridge/teaching/soft-eng/lect01.pdf

Performance

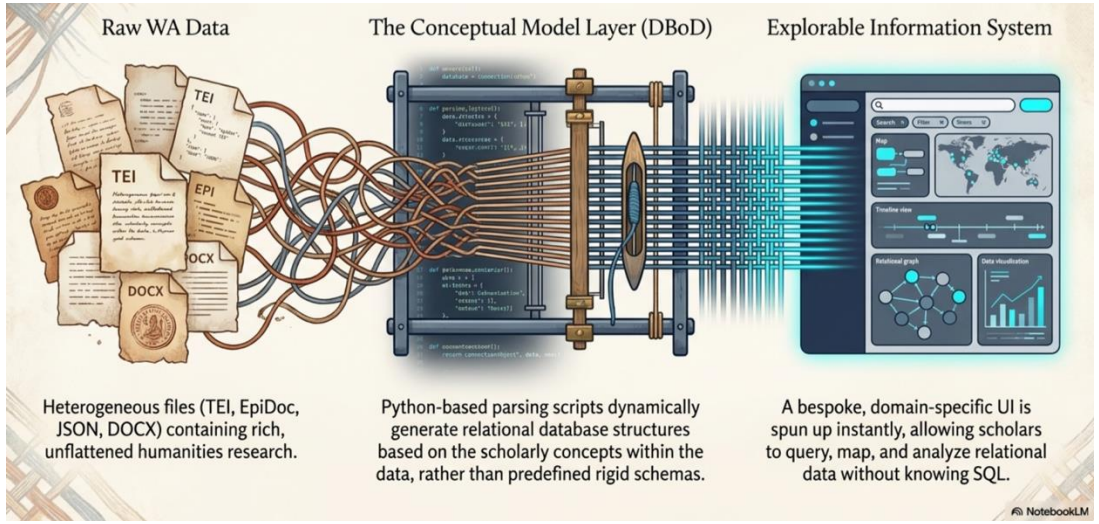
- Some systems must operate extremely efficiently
- Optimization improves speed and resource usage
- High-performance systems require specialized solutions
- Optimization often increases system complexity
- Optimized code can become harder to understand
- Highly specialized systems are less flexible
- Performance improvements often create tradeoffs
- Premature optimization often creates

- Better Performance, BUT
  - harder maintenance
  - reduced readability
  - reduced flexibility
- Example
  - Scientific simulations
  - Real-time systems
  - Large-scale databases

Maximum performance often reduces simplicity and maintainability

Ease of Reuse

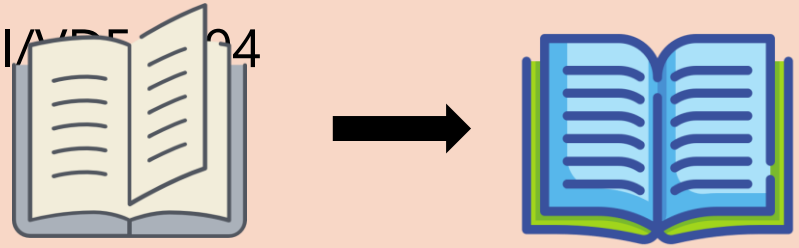
- Reuse reduces development effort
- Reusable components improve reliability
- Existing solutions can be adapted to new systems
- Reuse accelerates software development
- Modular architectures support reuse
- Separation of concerns is essential
- Systems should be designed with reuse in mind



Process models

PRODUCT REQUIREMENTS DOCUMENT →SCOPE MANAGEMENT PLAN

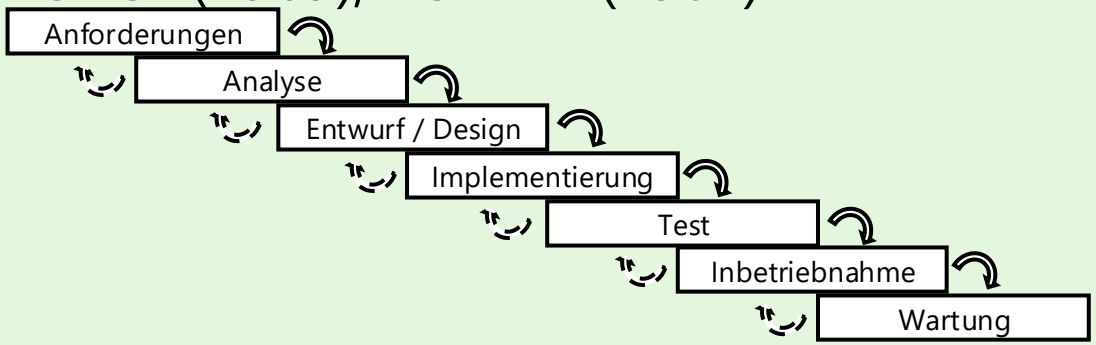
VDI/VDE 2194



WHAT (FOR)? → HOW?/WITH WHAT?

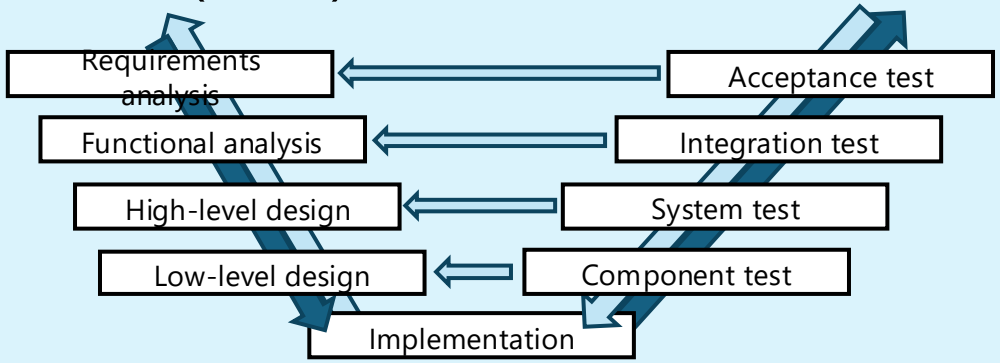
WATERFALL MODEL

ROYCE (1969), BOEHM (1981)



V-MODEL

BUND (1992)



SPIRAL MODEL

TAYLOR (1956), BOEHM (1980)

Icons made by Freepik from www.flaticon.com

Process models

„A completed airplane in many ways is a compromise of the knowledge, experience and disires of many engineers that make up the various design and production groups of an airplane company."
– C.W. Miller

https://slideplayer.com/slide/11577776/

Challenges in Research Contexts

Research requirements constantly evolve

Data are uncertain and heterogeneous

Research workflows are exploratory

Interpretations change over time

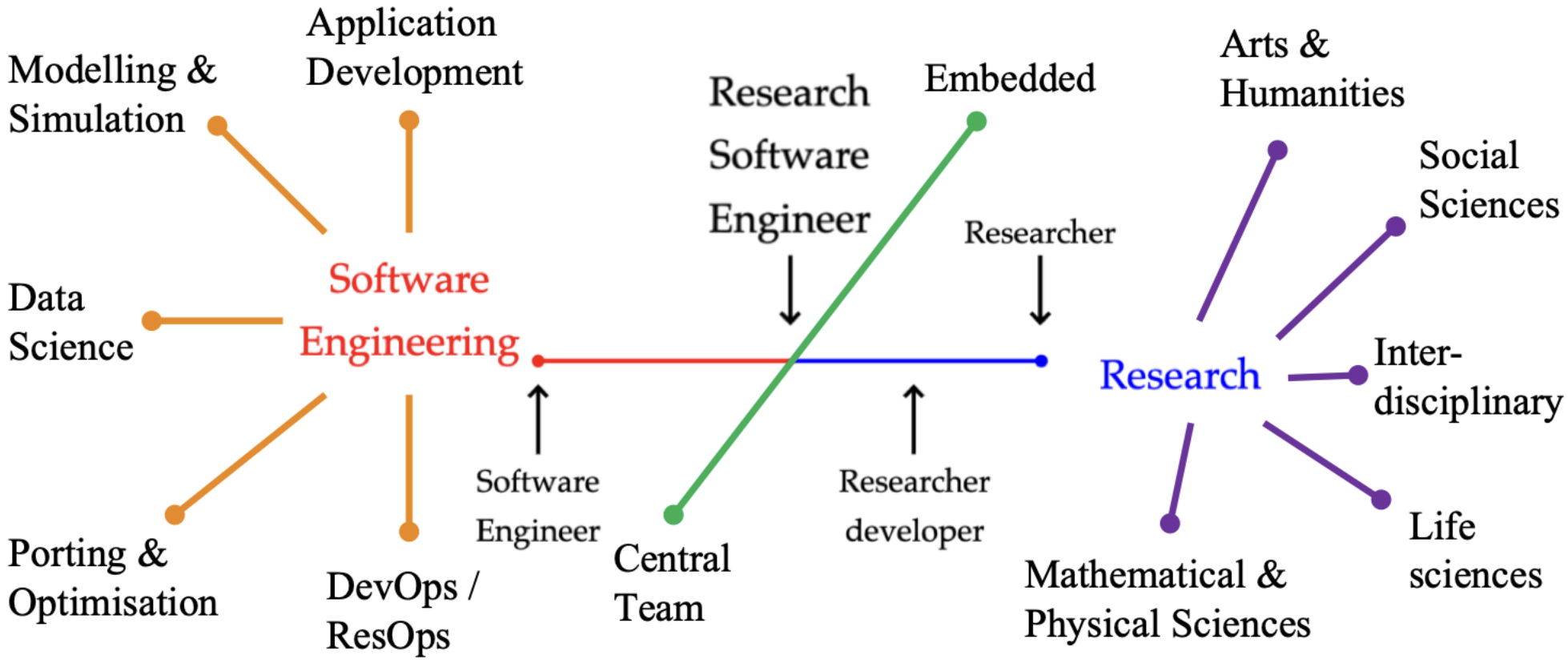
Domain expertise becomes central

Reproducibility is essential

Sustainability is often difficult

Problem: Classical SE alone is insufficient for research contexts

Software Engineering and Research



Chue Hong, Neil (2023). Is Research Software Engineering coming of age?, https://doi.org/10.6084/m9.figshare.24078054

Research Software

- **Research Software** includes source code files, algorithms, scripts, computational workflows and executables that were created **during the research process or for a research purpose**.
- **Software components** (e.g., operating systems, libraries, dependencies, packages, scripts, etc.) **that are used for research**, but were not created during or with a clear research intent should be considered software in research and not Research Software.

Gruenpeter, M., Katz, D. S., Lamprecht, A.-L., Honeyman, T., Garijo, D., Struck, A., Niehues, A., Martinez, P. A., Castro, L. J., Rabemanantsoa, T., Chue Hong, N. P., Martinez-Ortiz, C., Sesink, L., Liffers, M., Fouilloux, A. C., Erdmann, C., Peroni, S., Martinez Lavanchy, P., Todorov, I., & Sinha, M. (2021). Defining Research Software: a controversial discussion (Version 1). Zenodo. https://doi.org/10.5281/zenodo.5504016

Research Software Engineer

- The **Researcher Developer** wants to be judged on their scientific output, is a researcher at heart, however develops a lot of code due to the nature of their research. They would like recognition comparable to a research paper for a software implementation taken up by others.
- The **Research Software Engineer** comes from a research background but is also a skilled software developer, and relishes challenge of not just developing code to solve a problem but doing it well. They want to be recognized for producing tools which others rely on for research.

Robert Baxter, Neil Chue Hong, Dirk Gorissen, James Hetherington, Ilian Todorov: **The Research Software Engineer,** Digital Research, UK, 2012, https://www.research.ed.ac.uk/files/65195747/DR2012_12_1_.pdf

Preview

Analyst Developer Analyst Programmer Analyst Programmer - SITS (x 3) Analyst/Programmer Applications Developer Applied Scientist Architectural Robotics Developer Assistant Data Programmer Assistant Project Manager Atmospheric Correction and Radiative Transfer Model Scientist Audio Software veloper - KTP Associate Bioinformatician Bioinformatician In Potato Genomics and Genetics Bioinformatician/Computational Bioscientist in Microbiology Bioinformaticians Bioinformatics Analyst Bioinformatics Postdoctoral Researcher Bioinformatics scientist Biometric Software Systems Developer Biorespository Software Developer C++ / 3D Graphics Software Engineer Casebooks Project Editor (Research Assistant/Associate) Climate Researcher (Research Associate) Clinical Study Programmer CoMPLEX Research Associate Computational Biologist / Bioinformatician Computational Scientist Computational Scientist in Computational Fluid Dynamics & Industrial Applications Computational Scientist in Structural Mechanics and Industrial Applications Computer Scientist Computer Vision Researcher Content Developer/Programmer Control Engineer-IMG - 3 posts CREATe Data Specialist Data Analyst Data Integration Coordinator Data Manager x3 Database and Software Engineer Database Manager/Researcher Database Programmer Digital Media Technician E-Learning Portal Manager (KTP Associate) e-Learning Systems Development Analyst e-Learning Systems Development Analyst (Moodle, SQL) E-Learning Web Developer E-Portfolio Learning Technologist Embedded Systems Engineer Engineering Technician Environmental Scientist EPSRC Studentship on Algorithmic Construction of Finsler-Lyapunov Functions Experimental Officer in Bioinformatics Experimental Psychologist Finance Assistant Gaia Alerts Software Developer Gaia Software Developer (Gaia UK Team) GIS Applications Specialist Graduate Programmer / Software Developer Graphics Programmer Health Data Manager / Scientist High Throughput Bioinformatician High Throughput Sequencing Bioinformatician (Two posts) HIVE Manager/ HIVE Co-ordinator HIVE Senior Researcher and Technical Lead Hydro-informatics Scientific Software Developer Image Analysis Manager for Cancer Imaging Information Systems Developer Instrumentation Engineer Investigator Statistician IT Developer IT Services Manager IT Services Specialist (e-Learning Systems) IT Support Technician (Unix / Windows Systems) Knowledge Transfer Partnership (KTP) Associate: Innovent Technologies LTD Knowledge Transfer Partnerships (KTP) Associate - Software Deve KTP Associate Robot Vision Scientist (Research Fellow) KTP Associate (Fixed Term Contract for 24 months) KTP Associate (Precision Agriculture Data Analyst KTP Associate â€" Grad Developer KTP Associate: Electronics / Robotics Engineer Learning Technologist Leicester Respiratory BRU IT Developer Linguist / Psychologist Master Mariner Technician Marie Curie Early Stage Researcher Marie Curie Early Stage Researcher in Radar Rainfall for Integrated Water Quality Modelling Marine Earth Observation Scientists Medical Statistician Medical Statistician/Senior Medical Statistician Metrology Engineer Mobile Application Developer NASC IT Support - Programmer and Systems Administrator (Fixed-term) NIHR Research Methods Fellow PDRA on EU Project on Automated Multisensor Surveillance Planning Officer Policy Modeller 2014 Post - Doctoral Research Assistant INSTRON Post Doctoral Research Worker Post Doctoral Researcher in the application of Digital Technology Post-Doctoral Research Assistant in Simulation and Visualization Post-Doctoral Research Associate Post-Doctoral Research Associate (Pathogen Genomics) Post-Doctoral Research Fellow Postdoctoral Fellow – population genetics / evolutionary genetics Postdoctoral Fellow in Bioinformatics Postdoctoral Fellow in Cancer Therapeutics Postdoctoral Research Assistant Postdoctoral Research Associate Postdoctoral Research Fellow Postdoctoral Research Scientist Postdoctoral Researcher in Declarative (Logic and Functional) Programming Postdoctoral Researcher Postdoctoral Scientist Postdoctoral statistician Postdoctoral Training Fellow – Statistical and Computational Genetics of Autism Principal / Senior Bioinformatician Principal Bioinformatician Product Development Engineer (Rail) Publishing Portal Web Developer Radio Frequency Engineer Reader in Computer Science Reporting Analyst Research (Software) Engineer Research Assistant Research Associate Research Fellow Research Image Data Manager, Biomedical Engineering Research Officer Research Officer â€" Social Protection Research postgraduate Research Programmer Research Scientist Research Scientist / Senior Research Scientist Research Scientist in Machine Learning and Computer Vision Research Software Developer Research Software Developer for the Herchel Smith Professor of Organic Chemistry Research Software Engineer Research Studentship Research Worker Researcher SAP Trainee Technical Analyst Scientific Officer with Michela Garofalo Scientist SEAHA Studentship: Extracting epidemiological data from collections SEEG Data Archive Manager Senior / Research Associate in Clinical Integration and Image Analysis for Fetal Surgery Senior Analyst Programmer (Business Analysis) Senior Analyst/Programmer Senior Bioinformatician Senior Bioinformatician / Bioinformatician Senior Computational Statistician – Spatial Models Senior Data Acquisition Scientist / Data Acquisition Scientist Senior Data Manager Senior Database Administrator Senior IT Developer Analyst Senior Mathematical Modeller Senior Media Developer Senior Postdoctoral Researcher - Evolutionary and Computational Analysis of Infectious Disease (Phylodynamics) Senior Research Assistant Senior Research Associate Senior Research Associate â€" Molecular Modelling & Simmulation Senior Research Associate in Quantitative Clinical MRI Senior Research Fellow Senior Research Fellow/Research Fellow in Vibration Diagnostics and Prognostics/Digital Signal Processing Senior Research Laboratory Technician Senior Research Technician Senior Software Developer in Bioinformatics Se ator Senior Technician /

194 different job titles

Brett, A. (2020, November 30). Research Software Engineering: the growth of a movement.

A not-so-brief history of Research Software Engineers

Posted by s.aragon on 17 August 2016 - 2:26pm

By Simon Hettrick, Deputy Director

By Simon Hettrick, Deputy Director

On a beautifully sunny day in March 2012, a small group met at Queen's College Oxford and challenged a long-standing problem: why is there no career for software developers in academia? They didn't know it at the time, but this meeting led to a nationwide campaign that created a vibrant and rapidly growing community, and established a new role in research: the Research Software Engineer.

History

- 2012 RSE term usage and 1st RSE group established
- 2014 UK RSE Association
- 2016 1st UK RSE conference & de-RSE founded
- 2016 FORGE workshop “sustainable research applications and software” at U Hamburg
- Smith et al. (2016) Software Citation Principles https://doi.org/10.7717/peerj-cs.86
- 2017/18 Dutch + Nordic + US RSE Associations launched
- 2018 Software Management Recommendations (Alliance DE research org)
- 2022 FAIR Principles for Research Software (FAIR4RS)
- …

Struck, A. (2025, July 16). Research Software and its Engineers. RSE Day, Hamburg. Zenodo. https://doi.org/10.5281/zenodo.15959157

FAIR4RS – FAIR for Research Software

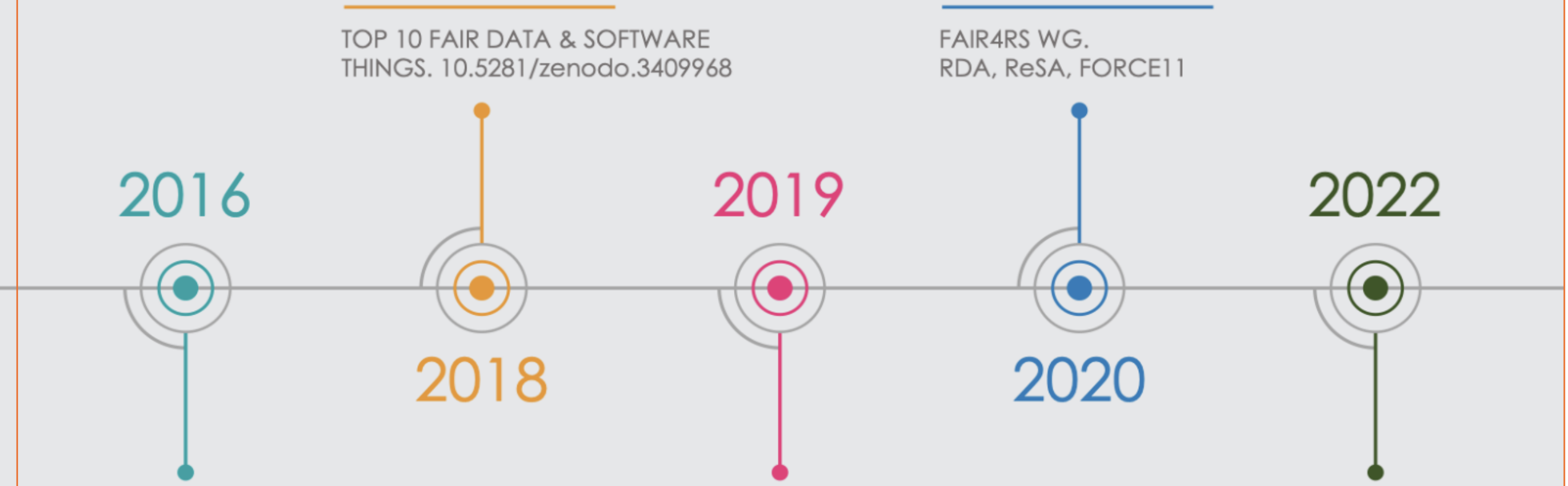
- less known/implemented than FAIR data principles
- referenced by ReSA, funders, research org, RSEs, training initiatives, …, (https://doi.org/10.5281/zenodo.10816031)
  - mostly alignment but not required
- several FAIR assessment tools suggested / implemented
  - diverse interpretations lead to diverging FAIRness scores in various implementations, example: https://github.com/fair-software/howfairis
- more: https://zenodo.org/communities/fair4rs/

Struck, A. (2025, July 16). Research Software and its Engineers. RSE Day, Hamburg. Zenodo. https://doi.org/10.5281/zenodo.15959157

Preview

FAIR FOR RESEARCH SOFTWARE

Martinez, P. (2023, February 21). FAIR4RS - FAIR for Research Software. Zenodo. https://doi.org/10.5281/zenodo.7660245



DOI: 10.5281/zenodo.7660245

Research Software Engineering (RSE)

RSE integrates software development into research practice

Research requirements evolve continuously

Research data are heterogeneous and uncertain

Software becomes part of the knowledge process

Domain experts and developers collaborate closely

Reproducibility and sustainability are core goals

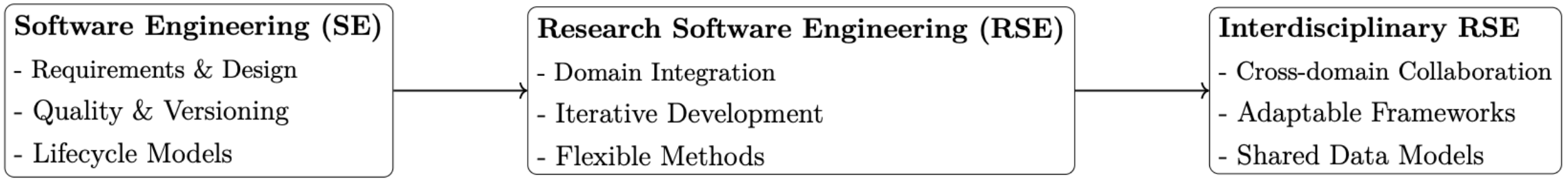
RSE combines technical and epistemic perspectives

The Future of RSE

- Code is **not a condensed method** or self-contained representation of a research method
- Research methods express **epistemic goals and interpretive frameworks**, whereas code implements technical and operational decisions
- Software embodies **assumptions, abstractions, and constraints** that extend beyond methodological description
- Research software is typically developed within **limited project durations**, often around **three years**
- Sustainability, documentation, and maintainability are essential to **enable future reuse**

RSE

- Research Software Engineering (RSE) emerged as a recognized field in the 2010s
- RSE combines software engineering expertise with domain-specific research
- Existing RSE initiatives focus strongly on:
  - Reproducibility
  - Sustainability
  - research infrastructure
  - FAIR principles
- Important organizations and initiatives include:
  - The UK Research Software Engineer Association
  - The Software Sustainability Institute
  - Netherlands eScience Center
  - Research Data Alliance (RDA)
- Existing approaches mainly focus on technical sustainability
- Interdisciplinary humanities research additionally requires:
  - interpretive flexibility
  - heterogeneous data integration
  - epistemic transparency



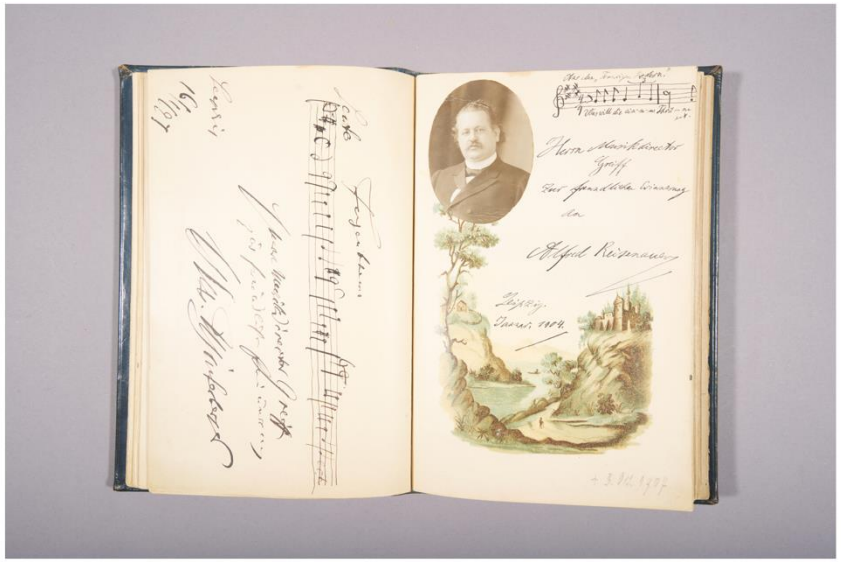
From SE to Interdisciplinary RSE

From SE to Interdisciplinary RSE

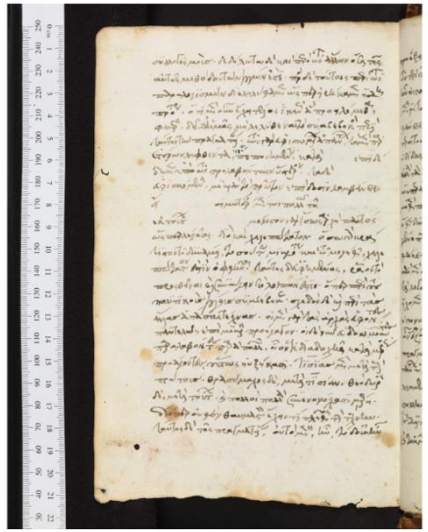
- Interdisciplinary projects involve **multiple epistemologies**
- Different disciplines use **different terminologies**
- **Shared computational environments** are required
- **Data models mediate** between disciplines
- **Communication** becomes a central infrastructure
- **Flexible frameworks** are necessary
- Interdisciplinary RSE enables **integration** across domains

UWA II: Project Groups Examples

PG Writing the Family: Genealogical Written Artefacts in Africa, Asia, and Europe

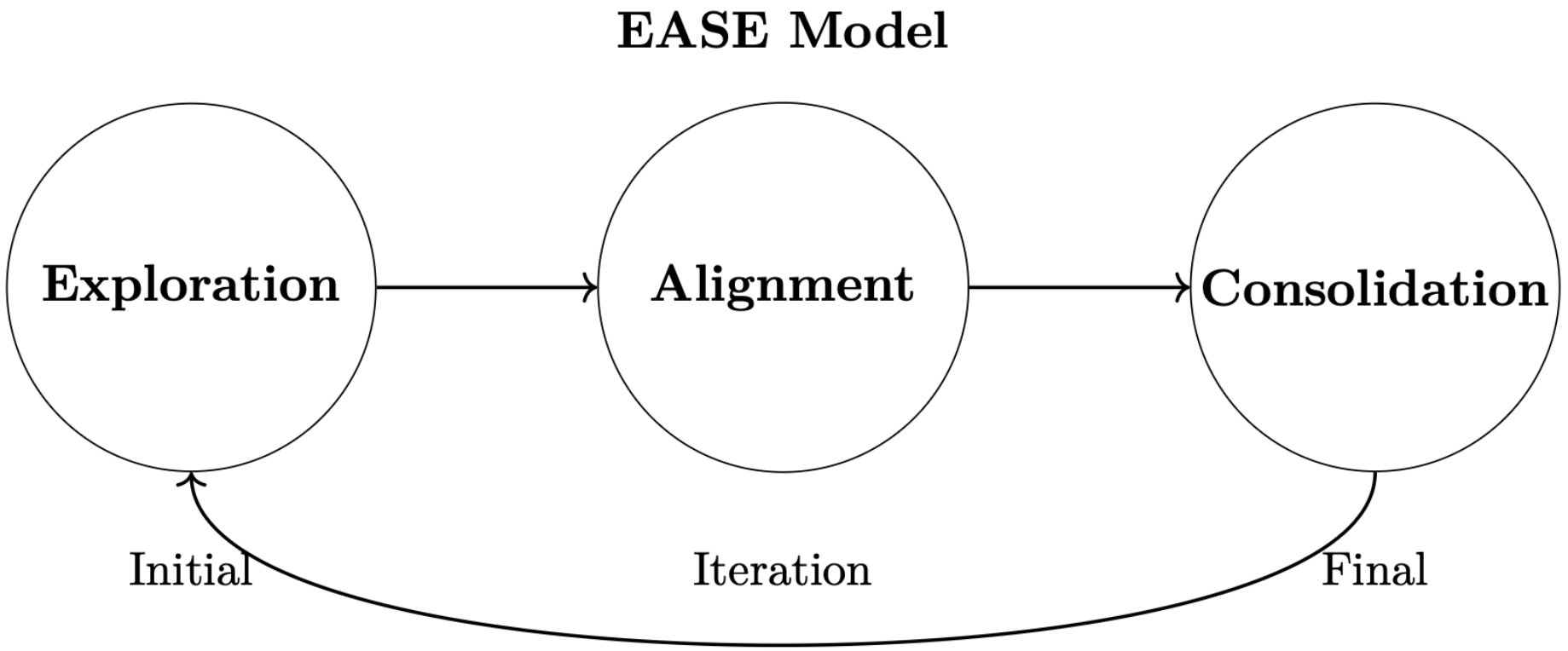


PG Provenancing Plant-Based Writing Supports



https://www.csmc.uni-hamburg.de/research/uwa-ii.html

Interdisciplinary RSE in Practice



The EASE Approach

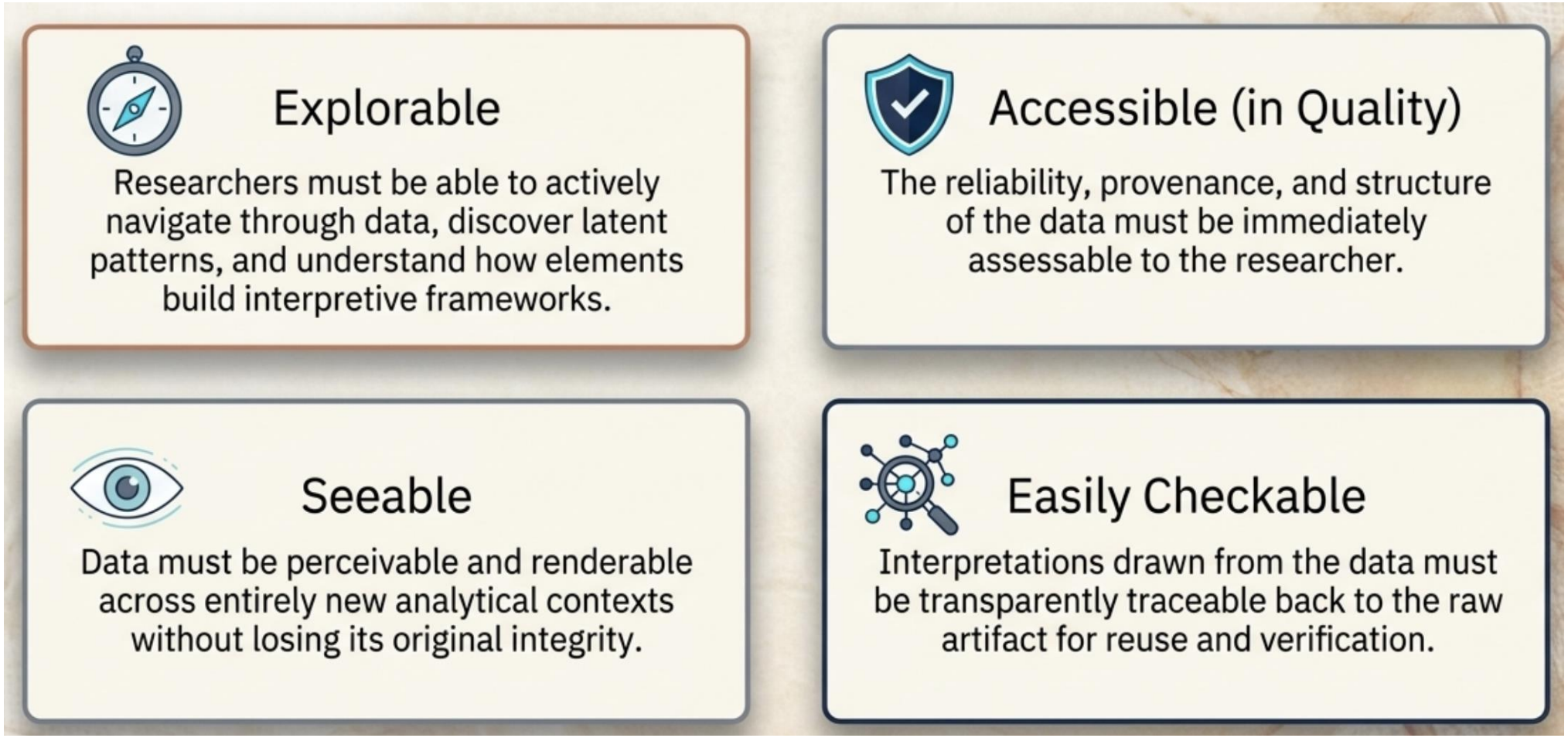


Image Generation: NotebookLM

Interdisciplinary RSE: Exploration

This phase focuses on establishing a shared understanding of the data and the research context.

- Researchers and RSEs collaborate early as equal partners
- Align research questions, expectations, and available data
- Identify heterogeneous data sources and domain-specific requirements
- Clarify formats, workflows, infrastructure, and expected data growth
- Balance technical feasibility with scholarly practices

Interdisciplinary RSE: Exploration

- Develop a shared conceptual data model for heterogeneous research data
- Define workflows for data organization, publication, and FAIR reuse
- Establish conventions for data collection, naming, and annotation
- Define guidelines to ensure consistency across contributors and disciplines
- Implement backup and data management strategies from the outset

Interdisciplinary RSE: Alignment

This phase begins as soon as new findings, data or requirements make adjustments necessary, reflecting the inherently exploratory nature of research.

- Reassess requirements and intermediate results collaboratively
- Maintain continuous exchange between researchers and RSEs
- Refine data models and software components iteratively
- Improve mechanisms for linking, filtering, and integrating data
- Align development with technical constraints and research needs

Interdisciplinary RSE: Alignment

- Ensure interoperability with external platforms and standards
- Synchronize data across repositories and research systems
- Manage raw and processed data transparently
- Reduce inconsistencies through guidelines and documentation
- Apply version control and EASE-oriented SE practices

Interdisciplinary RSE: Consolidation

This phase focuses on stabilizing and curating results and preparing them for publication.

- Validate results, data structures, and dissemination strategies
- Curate data while preserving technical and scholarly integrity
- Clean and consolidate datasets for traceability and reproducibility
- Transform data into reusable and accessible research outputs
- Ensure consistent metadata, identifiers, and long-term availability

Interdisciplinary RSE: Consolidation

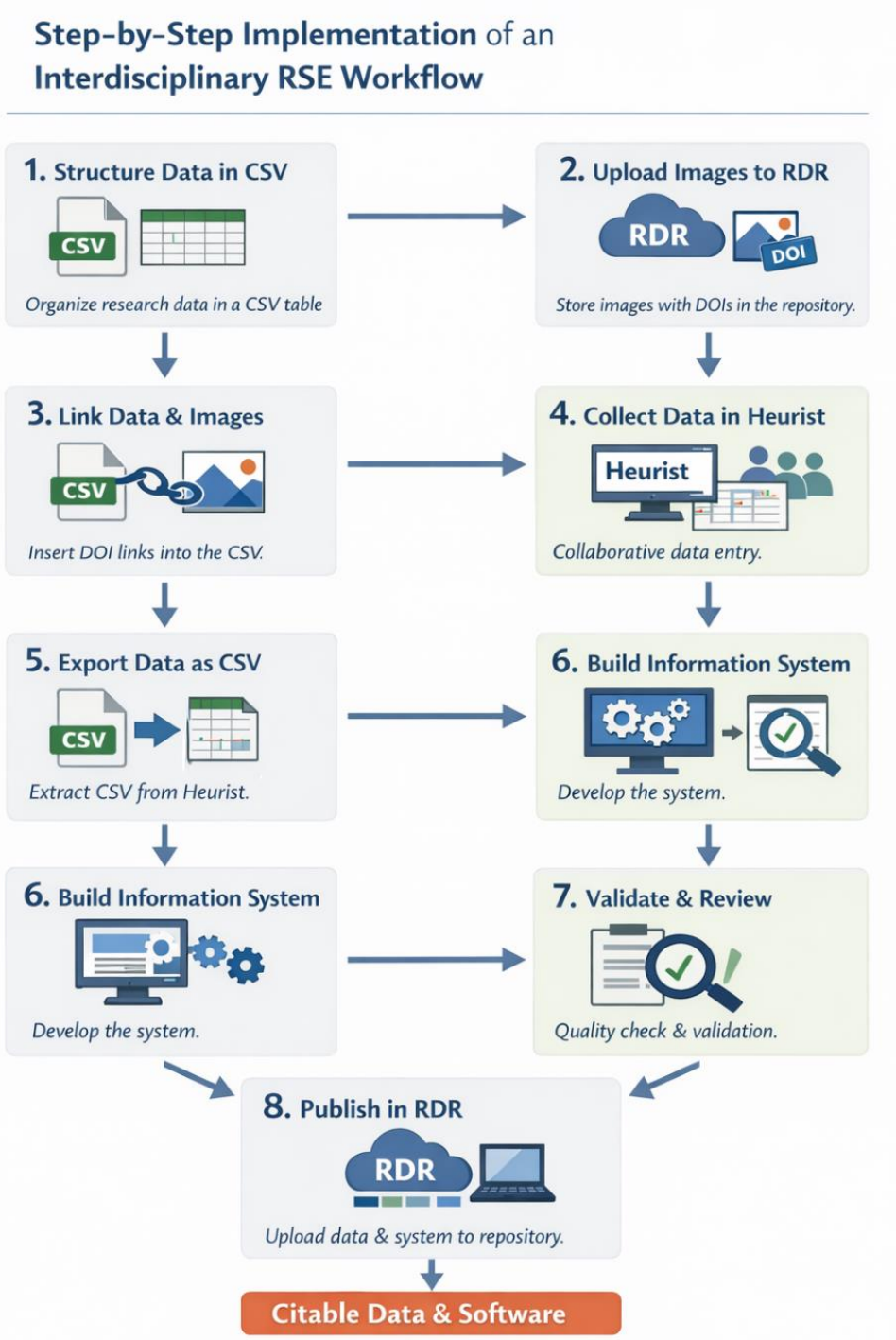
- Finalize publication and dissemination workflows
- Ensure FAIR compliance, interoperability, and long-term accessibility
- Align datasets and annotations with established standards
- Preserve domain-specific interpretative richness and context

Interdisciplinary RSE: Iteration

The iteration perspective **spans all project phases** and emphasizes that interdisciplinary RSE is not a linear process but a **continuous cycle of refinement, feedback, and adaptation**. Rather than being confined to a single phase, **iteration connects exploration, alignment, and consolidation** through recurring coordination, reassessment, and integration activities.

- Involve research software developers continuously as integral partners in the research process, rather than merely as technical support
- Treat research software and data as evolving, interdependent research objects shaped by both technical and epistemic considerations
- Base decisions on shared understanding of data, domain knowledge, and iterative communication rather than fixed project timelines
- Ensure at least three structured coordination meetings to support alignment across the entire project life cycle, iterative refinement, and task-specific consolidation
- Recognize RSE as a domain-oriented SE practice that bridges disciplinary boundaries and enables sustainable, reusable, and transparent research

Example: Workflow of an Interdisciplinary RSE at UWA I+II



Workflow of an Interdisciplinary RSE

Step 1: Structured Data Definition

A structured data model is defined during the initial meeting

Research data are organized in a tabular format (e.g., CSV), where each row represents a research object and columns define attributes, classifications, or references to external resources

Step 2: Image Publication in the RDR

Associated image data are uploaded to an RDR

Each image is assigned a DOI, ensuring long-term accessibility and citability

Step 3: Linking Data and Images

The generated DOIs are inserted into the CSV as URLs in dedicated fields

This creates a stable and explicit link between structured data entries and their corresponding digital images

Step 4: Collaborative Data Collection with Heurist

For data acquisition and curation, Heurist (e.g., hosted at UHH) is used as a collaborative RDM tool

This enables simultaneous data entry by multiple users and ensures structured and controlled data collection as well as automatic data backup via a centralized infrastructure

Workflow of an Interdisciplinary RSE

Step 5: Data Export and Standardization

Once data collection is completed, the dataset is exported from Heurist as a CSV file

This export serves as a standardized interface between data management and software development

At this stage, the second meeting takes place at the latest so that any necessary adjustments can be made

Step 6: Implementation of the Information System

Based on the structured dataset, an information system is implemented using a generic code base aligned with the EASE model

This allows modular development, iterative refinement, and direct integration of structured research data.

Step 7: Validation and Quality Assurance

The dataset and system are reviewed, cleaned, and validated to ensure consistency, completeness, and reproducibility

The third meeting should take place no later than this stage so that the final adjustments can be made

Step 8: Publication of Data and Software in the RDR

Both the dataset and the developed information system are deposited in the RDR

This ensures that the entire system becomes a citable research output, individual data entries (e.g., CSV rows) remain citable via linked DOIs, and the solution is reusable for future research contexts

Conclusion

- Sustainable software enables sustainable research
- Interdisciplinary collaboration is central to RSE
- Reproducibility and reuse require long-term thinking