bead

a provenance tool

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The Editor Gives You One Week

You need to:

1. Address reviewer concerns about source data
2. Redo analysis with new data
3. Recreate Figure 1
4. Submit within one week

But the Submission Was Months Ago

- Research submitted months ago
- Team has been improving data cleaning since then
  - Some team members left
- Different statistical methods now
- **First question**: How *exactly* was Figure 1 produced?

Research Results are Functions

$$\text{Figure 1} = \text{code}(\text{data})$$

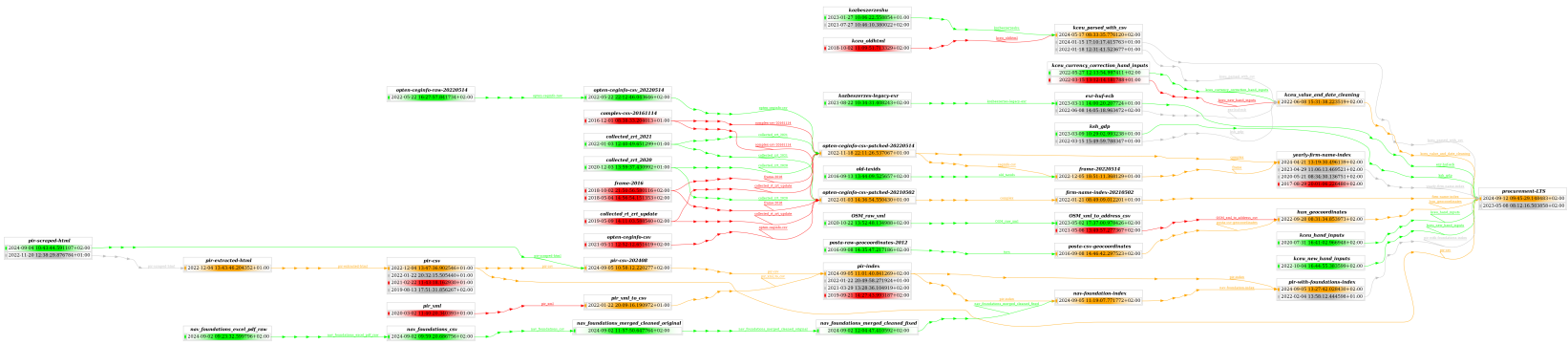
- Results depend on both algorithms and data
- Code under version control (Git)
- Tagged commit at submission
- **But what about the data?**

Data is Also a Function

$$\text{data}_1 = \text{code}_2(\text{data}_2)$$

- Data transformed by wrangling/cleaning steps
  - countries dropped
  - transformations applied
  - feature engineering details
- **Chain of data provenance**

A Real-World Data Pipeline



The Data Provenance Problem

Why It Is Complex:

1. **Frequent changes**: Code and data both evolve
2. **Complex pipelines**: Many steps, multiple datasets
3. **Tool heterogeneity**: Python, R, SQL, DuckDB all in one project
4. **Team dynamics**: People join, leave, change roles

Existing Solutions

Version Control (Git)

- Great for code
- **Not suitable for large binary data**

Data Version Control (DVC)

dvc.org

- Similar spirit to bead, but delivery/versioning focused
- **More complex than needed for provenance tracking**

Orchestration Tools

- Apache Airflow (Python) - airflow.apache.org
- dbt (SQL) - getdbt.com
- KNIME (no-code) - knime.com
- **Too complex for heterogeneous teams**

Enter bead

A command-line tool that captures your data's story, step by step.

- Much simpler than alternatives
- Language agnostic
- Supports heterogeneous teams

What bead Does NOT Do

Not a code runner

- You run your own code
- Python, R, Stata, SQL - doesn't matter

Not a file delivery system

- File system stores your files
- You copy/move files yourself

Only requirement:

- Works with flat files on file system
- Files not too big (20GB works fine)

Core bead Concepts

The bead

- Self-contained unit of computation
- Contains code, *reference* to input data, results
- Packaged as ZIP file
- Remembers exact provenance

Simple Commands

```
bead new my-analysis
bead input add source-data
bead save
```

Demo Time

Inspiration

- Data Journalism
- Human concept of story
  - Characters, setting, events, theme or message
  - Variable scope
  - Stories are composable
  - Helps us to make sense of the world

Design

- ISBN / ISSN
  - Identification of books and series with code
- Task scope
- Local first
- Integrity

Demo

Conference session classification by title

Inputs:

- list of sessions
- session theme classification rules

Output:

- list of sessions extended with theme

Workspace and Box

Output: Plain data

Workspace

- name (*sessions*)
  - input
  - output
  - temp

Calculation 1: CSV to DuckDB

Calculation 2: Match Themes

Versions: Inputs and Improvements

Visual Overview

Visual Overview

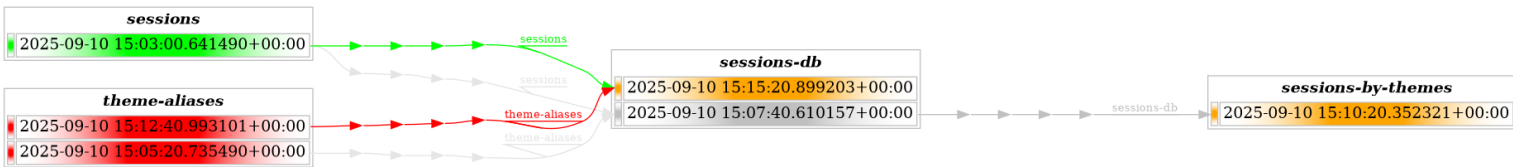


Figure 1: session-themes.png

Internal Details

Internal Details

Similar ideas

Similar ideas

- kaggle notebook
  - https://www.kaggle.com/code#:~:text=New,-Notebook
- nix flake
  - https://nixos.wiki/wiki/Flakes#Flake_schema
- orderly2 (RSECON24 talk)
  - https://youtu.be/IkPgihFQbrk

Source

Source

https://github.com/e3krisztian/bead {{< qrcode https://github.com/e3krisztian/bead qrgithub 300 300 >}}

Case Study From Our Research Lab

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- Used since 2017 in our research groups: CEU MicroData, MACROMANAGERS.eu
  - internally
  - when sharing data with others
- Saved about 600+ beads, two versions on average
- Interquartile range of bead sizes: 10 to 500 MB, largest is 23 GB
- Median time between saving new versions: 51 days

Practices We Adopted

- *Everything* is a bead: raw data, intermediate data, analysis sample, research results
- Never load data directly, from outside a bead
  - Side product: always use relative paths
- We don't often recompute everything, but good to know we *could*

Lessons For Research Software Engineers

- Minimal learning curve for researchers
- No infrastructure requirements
- Works with existing workflows
- Complements version control
- Enables true reproducibility

Key Takeaways

1. **Data provenance is hard** - especially with changing teams
2. **Existing tools too complex** - for heterogeneous research teams
3. **bead keeps it simple** - focuses on one thing well
4. **Reproducibility becomes automatic** - not an afterthought

Contact and Acknowledgements

- Web: bead.zip
- Installation: https://bead.zip/install
- GitHub: github.com/e3krisztian/bead

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References

- **World Development Indicators**: data.worldbank.org/indicator
- **DVC (Data Version Control)**: dvc.org
- **Apache Airflow**: airflow.apache.org
- **dbt**: getdbt.com
- **KNIME**: knime.com