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Provenance as a Bridge Between Data Analysis Modalities



VISUAIZATION design lab

THE UNIVERSITY OF UTAH





ACKNOWLEDGEMENTS



Kiran Gadhave

Phillips, Marc Streit, Nils Gehlenborg



CAREER: Enabling Reproducibility of Interactive Visual Data Analysis



Zach Cutler

Also: Jochen Görtler, Carolina Nobre, Oliver Deussen, Miriah Meyer, Jeff

WHAT IS PROVENANCE?

Provenance (from the French provenir, 'to come from/ forth') is the chronology of the ownership, custody or location of a historical object. [Wikipedia]

In CS: a log, a record of everything that lead to a state

PURPOSES FOR PROVENANCE

	Purposes for Provenance
Recall	Maintaining or recovering men current and previous states of t
Replication	Reproducing the steps or work
Action recovery	Maintaining the action history operations and branching actio
Collaborative communication	Communicating and sharing da with others who are conducting
Presentation	Communicating the insights or with those who are not directly themselves, such as general pul management, or analysts focus
Meta-analysis	Reviewing the analytic processe understand and improve aspect process efficiency, training effic strategies)

[Ragan et al 2015]

nory and awareness of the the analysis

flow of a previous analysis

that allows undo/redo ons during analysis

lata, information, and ideas g the same analysis

progression of the analysis involved with the analysis blic, upper levels of sing on other areas

es themselves in order to ets of the analysis (such as ciency, or analytic

Re-Application

[Xu et al 2020]

Convert the user interactions into executable scripts.

PROVENANCE AS A BRIDGE BETWEEN DATA ANALYSIS MANAL TIES

What are Modalities? **Interactive Visualization Systems**

Code / Scripting



INTERACTIVE VISUALIZATION

Intuitive Easy to use Uses human perceptual capabilities

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	2		Emiliano Rigoni		RUS - Pre	Zenit St. Peters		W
	3		Sebastián Driussi		RUS - Pre	Zenit St. Peters		CF
	4		Aleksandr Kokorin		RUS - Pre	Zenit St. Peters		CF
	5		Anton Zabolotnyi		RUS - Pre	Zenit St. Peters		CF
	6		Quincy Promes		RUS - Pre	Spartak Mosco		W
	7		Pedro Rocha		RUS - Pre	Spartak Mosco		W
	8		Lorenzo Melgarejo		RUS - Pre	Spartak Moscov		W
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	17		Andrei Ivan		RUS - Pre	FK Krasnodar		W
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	20		Fedor Smolov		RUS - Pre	FK Krasnodar		CF
	21		lvan Ignatjev		RUS - Pre	FK Krasnodar		CF
	22		Alan Kasaev		RUS - Pre	Lokomotiv Mos		W
	23		Jefferson Farfán		RUS - Pre	Lokomotiv Mos		W
	24		Arshak Koryan		RUS - Pre	Lokomotiv Mos		W
	25		Éder		RUS - Pre	Lokomotiv Mos		CF
	26		Ari		RUS - Pre	Lokomotiv Mos		CF
	27		Gökdeniz Karadeniz		RUS - Pre	Rubin Kazan		W
	28		Rifat Zhemaletdinov		RUS - Pre	Rubin Kazan		W
	29		Sardar Azmoun		RUS - Pre	Rubin Kazan		CF
	30		Léo Jabá		RUS - Pre	Akhmat Grozny		W
	31		Bernard Berisha		RUS - Pre	Akhmat Grozny		W
	32		Magomed Mitrishev		RUS - Pre	Akhmat Grozny		W
	33		Odise Roshi		RUS - Pre	Akhmat Grozny		W
	34		Khalid Kadyrov		RUS - Pre	Akhmat Grozny		W
	35		Bekim Balaj		RUS - Pre	Akhmat Grozny		CF
	36		Ablaye Mbengue		RUS - Pre	Akhmat Grozny		CF
	37		Zaur Sadaev		RUS - Pre	Akhmat Groznv	7	CF



INTERACTIVE VISUALIZATION: DOWNSIDES

Limited Expressivity Some operations are difficult

e.g., conditional queries. Not reusable

need to redo analysis when data changes Not reproducible



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	37		Zaur Sadaev		RUS - Pre	Akhmat Groznv		CF



CODE/SCRPTING

Flexible and powerful you basically can do anything Reusable if your data changes, re-run Reproducible everything is documented

1	# Keep
2	avy_df
3	
4	# Remov
5	avy_df
6	
7	# Split
8	avy_df[
9	
10	# Remov
11	avy_df
12	avy_df
13	
14	# Keep
15	avy_df
16	avy_df.

```
this cell
= pd.read_csv('./avalanches.csv')
e NaN coordinates
= avy_df[avy_df['Coordinates']==avy_df['Coordinates']]
into latitude & longitude
['lat', 'lon']] = avy_df['Coordinates'].str.split(',', expand=True)
ve values outside of Utah bounds
= avy_df[ (36 < avy_df['lat'].astype('float')) & (avy_df['lat'].astype('float') < 42)]</pre>
= avy_df[(-114 < avy_df['lon'].astype('float')) & (avy_df['lon'].astype('float') < -108)]</pre>
columns we need
= avy_df[['Date', 'Region', 'Trigger', 'lat', 'lon']]
head (
```



CODE / SCRIPTING: DOWNSIDES

It's hard requires extensive training reading documentation not discoverable Not everyone can do it It's time consuming Some operations are difficult e.g., labeling data points

1 # Keep this cell 13 16 avy_df.head()

```
2 avy_df = pd.read_csv('./avalanches.csv')
   # Remove NaN coordinates
   avy_df = avy_df[avy_df['Coordinates']==avy_df['Coordinates']]
 7 # Split into latitude & longitude
   avy_df[['lat', 'lon']] = avy_df['Coordinates'].str.split(',', expand=True)
    # Remove values outside of Utah bounds
   avy_df = avy_df[ (36 < avy_df['lat'].astype('float')) & (avy_df['lat'].astype('float') < 42)]</pre>
12 avy_df = avy_df[(-114 < avy_df['lon'].astype('float')) & (avy_df['lon'].astype('float') < -108)]</pre>
   # Keep columns we need
15 avy_df = avy_df[['Date', 'Region', 'Trigger', 'lat', 'lon']]
```



COMPUTATIONAL NOTEBOOKS: A MIDDLE GROUND?



Observable



R Markdown

Jupyter Notebooks

COMPUTATIONAL NOTEBOOKS: A MIDDLE GROUND?

Yes Afford both scripting and interactive visualization But visualizations are a dead end can't "use" interaction in code e.g., changing a label, or filtering a value



Jupyter Notebooks

THESIS: BRIDGING BETWEENCODE AND VIS IS USEFULUse the best tool for each job

THE ROLE OF PROVENANCE IN BRIDGING BETWEEN CODE AND VISUALIZATIONS

Root

Brush selection

Outlier selection

Filter

Rename column

Rename column

Provenance: record of actions that ead to a state > Design actions such that (some) map to code operations

Translate your actions to code OR Make code understand actions

INTERACTIVE WORKFLOWS



"Filter Outliers" Workflow

NOTABLE EXAMPLES FOR CODE SYNTHESIS



	File	Edit Vie	ew Inser	t Cell	Kernel C	Widgets Code	Help	•	Toggle 🔵	Toggle Mida	s 🗃 charts
In [1]:	from impos # In m = 1	midas im rt numpy <i>itiate Mi</i> Midas()	port Mida as np das envir	s onment						C/	AUSE_DESCR_fi
In [2]:	<pre># Lot fires</pre>	ad data s_df = m.	from_file	:("./data/1	fire_earl	ier.csv")				Jacobia de la companya de la company
Out[6]:	STATE		LATITUDE	LONGITUDE	FIRE_SIZE	CAUSE_C	ODE	CAUSE_DES	SCR DISCO	v	Debris Bu
	GA	Baldwin	33.0514	-83.0735	6.65		5	Debris Bur	ning 2	2.	
	WV	Monongalia	39.5665	-80.0572	5		5	Debris Bur	ning 2	2.	
	WV	Logan	37.9409	-82.023	61		10	Firewo	orks 2	2. 51	TATE_fires_df_d
In [3]: In [4]:	<pre># CAUSI CAUSI # STATI</pre>	06:40 PM E_DESCR_f 06:40 PM E fires d	ires_df_d	list = fire	es_df.gro	up('CAUS	E_DE	SCR').vis	5()		2,000 1,500 1,000 500
In [5]:	TAT	06:40 PM	E DESCR f	ires_df_di	ist": {"C	ALE).VL	S() CR":	["Arson'	']}}])		GA MS O

[Wu et al. 2020]





Wrangler

Import Export				
dine into		Tear Year	State	🗰 Pro
	0	Reported crime in Alabama	Alabama	
	. 1	2004	Alabama	4029.3
	2	2005	Alabama	3900
	3	2006	Alabama	3937
	4	2007	Alabama	3974.9
	5	2008	Alabama	4081.9
	6	Reported crime in Alaska	Alaska	
	7	2004	Alaska	3370.9
	8	2005	Alaska	3615
	9	2006	Alaska	3582
rom above	10	2007	Alaska	3373.9
Tom above	11	2008	Alaska	2928.3
able Clear	12	Reported crime in Arizona	Arizona	
	13	2004	Arizona	5073.3
	14	2005	Arizona	4827
rts with 🛛 🕀	15	2006	Arizona	4741.6
	16	2007	Arizona	4502.6
tains	17	2008	Arizona	4087.3
tams	18	Reported crime in Arkansas	Arkansas	
ositions 0 8	19	2004	Arkansas	4033.1
Jan 19 0, 0	20	2005	Autonean	1000

[Kandel et al. 2011]



CHALLENGE: MAKING WORKFLOWS ROBUST

WHAT ARE SELECTIONS?



FROM SELECTIONS TO **ADVANCED OPERATIONS**





Filter



Categorize



Unassigned

Category A

★ Category B





Interesting



ROBUST SELECTIONS UNDERPIN MOST INTERACTIVE OPERATIONS

Information Visualization 2021. Kiran Gadhave, Jochen Goertler, Alexander Lex, et al.

Less Robust

ROBUST SELECTIONS

More Robust



ID Based Selection: Elements 7, 9, 13, 18, 22 **Region-Based Selection:** Elements that are >1.5 in x and > 2 in y**Semantic Selection:**

improves reproducibility enables re-usability

Elements in K-Means cluster centered at [2, 3]

Meaningful, higher level concept: Robust to changes and updates in dataset:



LEVERAGING INTENT FOR ROBUST SELECTIONS

Intent is the user's reason for selecting in a visualization. Domain Specific Intent: Capture through Annotation Pattern-Based Intent: Capture Automatically



Outlier



Clusters



Categories

Clusters



Multivariate Optimization



Correlation



Ranges







Selection



Predictions



K-Means DBScan Regression Outlier Detection Skyline Decision Trees / Ranges Categories



Selection

Predictions

K-Means DBScan Regression **Outlier Detection** Skyline Decision Trees / Ranges Categories





Ranking Jaccard Distance Naive Bayes Classifier Heuristic Measures









Selection



Predictions

K-Means DBScan Regression Outlier Detection Skyline Decision Trees / Ranges Categories



I think this cluster...

Ranking Jaccard Distance Naive Bayes Classifier Heuristic Measures

Confirming Intent & Annotation







Visualization and Selection

http://vdl.sci.utah.edu/predicting-intent/

		Inte	ent	
	Please interact			
	Annotate			
		Predictions	me required: 0.01 seconds	
ot				
		Selec	tions	
	UNION			0 TOTAL
10				

Annotation of Intent and Predictions



	1

REFLECTION

Robustness is easier in code: of items.

workflows from interactions

developers write rules, rather than lists

Have to do extra work to get to the "rules" when trying to create robust





HOW CAN WE INTEGRATE MODALITIES IN PRACTICE?

SPECTRUM OF VISUALIZATION SYSTEMS

Generic Charting



Easy to integrate in notebooks

Specialized Systems







Require standalone application

EuroVis 2022. Kiran Gadhave, Zach Cutler, Alexander Lex

STANDALONE SYSTEMS USING WORKFLOWS

VISUALIZATION SYSTEM

Brush Type	
$\Box \circ \circ O$	0
	2e8
Fransforms	4e8 -
	6e8 –
	8e8 -
AGGREGATE	1e9 –
	1e9 -
Categories	1e9 1e9 1e9 3tion (number of
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Visualization Interface



Predictions

CLUSTER (0.823) **1**0 CLUSTER (0.701) **1** 0 **L O** CLUSTER (0.696) **L O** CLUSTER (0.687) **L** 0 CLUSTER (0.682) **\$ 0** CLUSTER (0.681) **L O** CLUSTER (0.672) **1** 0 CLUSTER (0.621) **1** 0 CLUSTER (0.424) POLYNOMIAL REGRESSION (0.411 LINEAR REGRESSION (0.393) **1** 0 \$ 0 OUTLIER (0.386) **L** O CLUSTER (0.381) **1** 0 CLUSTER (0.380) **1** 0 CLUSTER (0.372) **1** 0 OUTLIER (0.323) LINEAR REGRESSION (0.318) **1** 0

Provenance



WORKFLOW EDITOR

Interaction logs aren't clean

Need to tidy them up



REUSING SELECTIONS ON UPDATED DATASETS



HUMAN REVIEWS









WORKFLOWS: OPPORTUNITY FOR BRIDGING THE GAP

steps

Can be abstracted and re-used in different environments

> Bridging between our tool and Python





Interactive Visual Analysis



Library that tracks and re-executes actions

Computational Analysis



USING WORKFLOW IN A COMPUTATIONAL NOTEBOOK



Prints the reapply results for all interactions, along with review status.

а	modu	le	called	ba	icken	d
wh	ich	ini	tialize	s	the	library

we grab the final one. result_dataset

This workflow has not been reviewed for all interactions. Please go to following url: <u>https://reapply-workflows.gitk</u>

	Label	X	Y
3	P52	6.58351	7.28796
5	P171	4.77421	4.17980
8	P199	8.34966	0.09550
9	P183	8.42670	1.80299
10	P61	4.29760	2.99981
141	P138	7.35179	7.05215
142	P46	6.62171	8.27311

```
# Apply the workflow to target dataset.
# apply function requires the target dataset
# and the label column as arguments.
res = workflow.apply(target, "Label")
```

```
# Results is an array of datasets for each interaction
result_dataset = res.results[-1]['data']
```

BEFORE AND AFTER

150 rows × 3 columns



v

NO VALID SELECTIONS

REFLECTIONS

Useful for using a standalone system with updating data using scripting after using a standalone system creating template workflows (teaching)

SPECTRUM OF VISUALIZATION SYSTEMS

Generic Charting

Easy to integrate in notebooks

Specialized Systems

Require standalone application

TRACKING PROVENANCE IN INTERACTIVE PLOTS IN NOTEBOOKS

Interactive plots are now common in notebooks (e.g., Vega-Altair)

Operations such as filtering outliers or changing column labels are more efficient to do in interactive plots

PRINCIPLE

Track events in interactive visualizations

Map them to data frame operations

Operations then applied to data frame

"Listen" to all events by Vega-Altair works for all charts that can be created with Vega-Altair no extra effort on developer! **Custom table visualization for data** frames instead of df.head() -> use interactive table

VEGA-ALTAIR EXAMPLE

Standard Python and Vega-Altair Code

Plot Generated by Vega Altair

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[4]:		Name	mpg	Cylinders	Displacement	Horsepower	w_lbs	Acceleration	Year	Origin	annotations
	0	chevrolet chevelle malibu	18.0	8	307.0	130.0	3504	12.0	1970-01-01	USA	No Annotation
	1	buick skylark 320	15.0	8	350.0	165.0	3693	11.5	1970-01-01	USA	22-10-23 (20:11) - Test Annotation
	2	plymouth satellite	18.0	8	318.0	150.0	3436	11.0	1970-01-01	USA	22-10-23 (20:11) - Test Annotation
	3	amc rebel sst	16.0	8	304.0	150.0	3433	12.0	1970-01-01	USA	22-10-23 (20:11) - Test Annotation
	4	ford torino	17.0	8	302.0	140.0	3449	10.5	1970-01-01	USA	22-10-23 (20:11) - Test Annotation
	401	ford mustang gl	27.0	4	140.0	86.0	2790	15.6	1982-01-01	USA	No Annotation
	402	vw pickup	44.0	4	97.0	52.0	2130	24.6	1982-01-01	Europe	No Annotation
	403	dodge rampage	32.0	4	135.0	84.0	2295	11.6	1982-01-01	USA	No Annotation
	404	ford ranger	28.0	4	120.0	79.0	2625	18.6	1982-01-01	USA	No Annotation
	405	chevy s-10	31.0	4	119.0	82.0	2720	19.4	1982-01-01	USA	No Annotation

406 rows × 10 columns

[]: selection = alt.selection_interval("selector", encodings=["x", "y"]) scatterplot = alt.Chart(data).mark_point().encode(x="Miles_per_Gallon:Q", y="Weight_in_lbs:Q", color="Power:N").add_params(selection) barchart = alt.Chart(data).mark_bar().encode(y="Power:N", x="count()", color="Power:N").transform_filter(selection) scatterplot & barchart

```
x="Cylinders:0",
y="count()",
opacity=alt.condition(selection, alt.value(1), alt.value(0.5))
).properties(width=400, height=300).add_params(selection)
```

□ ↑ ↓ 古 ♀ ■

All datasets generated

TABLE EXAMPLE

[27]:	<pre>table = PR.vis.interactive_table(df) table</pre>								
[27]:	G	(2° []×	+ 88	7 7	E				
		index int64	Name object	Miles_per float64	Cylinders int64				
		1	chevrolet chev	18	8				
		2	buick skylark	15	8				
		3	plymouth satel	18	8				
		4	amc rebel sst	16	8				
		5	ford torino	17	8				
		6	ford galaxie 500	15	8				
		7	chevrolet impala	14	8				
		8	plymouth fury iii	14	8				
		9	pontiac catalina	14	8				
		10	amc ambassa	15	8				
	<<	< > >	>> Showing 1 -	10 of 406 entries					

6

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307	130	3504	12	0	USA	Root	
350	165	3693	11.5	0	USA		
318	150	3436	11	0	USA		
304	150	3433	12	0	USA		
302	140	3449	10.5	0	USA		
429	198	4341	10	0	USA		
454	220	4354	9	0	USA		
440	215	4312	8.5	0	USA		
455	225	4425	10	0	USA		
390	190	3850	8.5	0	USA		

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OPERATIONS

Editing column names, cells Sorting rows/columns Dropping rows/columns Filtering (in/out) items (with intent predictions) Labeling items **Categorizing items Grouping / Aggregating items**

REFLECTIONS

Fully reusable, just like code

User interaction when useful, use coding when more efficient!

Provenance enables undo/redo in notebook Branching enables alternative explorations Minimal invasiveness makes it easy to adopt

TAKE-AWAYS

Provenance can be used to bridge analysis modalities!

Translation to meaningful operation isn't always easy - more work needed!

Low-level charts are ripe target for integrating interactivity in notebooks

Alexander Lex Mastodon: <u>@alexlex@vis.social</u> http://alexander-lex.net

Hanspeter Pfister, and many others!

Thanks to: Kiran Gadhave, Zach Cutler, Carolina Nobre, Marc Streit, Jochen Görtler, Oliver Deussen, Miriah Meyer, Jeff Phillips, Samuel Gratzl, Holger Stitz, Nils Gehlenborg, Hendrik Strobelt, Romain Vuillemot,

VISUAIZATION design lab

THE UNIVERSITY OF UTAH

