

ManyFold: A Design Exploration of Data Visualization on Foldable Mobile Devices

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A - Major form factor categories and current commercial foldables

	Book-style	Clamshell	Tri-fold	Others
Samsung Galaxy Z Fold	x			
Samsung Galaxy Z Flip		x		
Samsung Galaxy Z TriFold			x	
Google Pixel Fold	x			
Honor Magic V	x			
Huawei Mate X	x			
Huawei Mate XT			x	
Huawei MateBook Fold				Foldable Laptop
Microsoft Surface Duo	x			2 separate inside-displays, 360° folding
Motorola Razr		x		
Motorola Razr Fold	x			
OPPO Find N	x			
OPPO Find N Flip		x		
Lenovo ThinkPad X1 Fold				Foldable Laptop
ASUS Zenbook Fold				Foldable Laptop
OnePlus Open	x			

A non-exhaustive selection of commercial foldable product lines, illustrating the major form-factor categories discussed in Section 2. These devices were one of several resources informing the construction of our device-centered design space (Section 3).

B – Workshop consent form

Consent form

to participate in a workshop and to record personal data for research purposes.

The research project "ManyFold" aims to investigate data visualization for foldable devices. For the exclusive purpose of the above-mentioned research, an ideation workshop will be conducted by [REDACTED]

[REDACTED] A voluntary and informed consent is required for this.

Data processing

The declaration of consent covers the processing of the following personal data:

Age, gender, educational background, personal experience/expertise on areas related to the project topic, personal ideas and opinions on the project topic, as well as photo, audio, and video recordings during the study.

Anonymity

The data gathering, processing, and storage take place under a pseudonym (test person code) and separately from this declaration of consent. However, under certain circumstances and in individual cases, it may not be possible to make the data completely anonymous or to draw conclusions about you on the basis of the data collected.

Data transfer

Unless otherwise provided by law or unless you have expressly consented in individual cases, no personal data will be transmitted to third parties.

Publication

The research results are published in the usual scientific form. We assure that no conclusions about natural persons can be drawn from the publications.

Voluntariness and withdrawal

Participation in the research project is voluntary. Non-participation has no negative consequences for you. This consent can be withdrawn at any time in writing and informally at the data gathering institution and with effect for the future. In this case, the collected data will be deleted. In individual cases, the deletion of archived or already scientifically published data is not possible in full.

Duration of data storage

The collected data will be stored indefinitely or until withdrawal.

Data protection officer and supervisory authority for data protection

I am aware that I can contact the data protection officer of [REDACTED] as well as the responsible supervisory authority for data protection [REDACTED] at any time.

Right of access to information

I am aware that I may at any time request information about the data processed concerning my person and the possible recipients of this data to whom they have been transmitted and that I am entitled to an answer with the period of one month after receipt of the request for information.

1. Confirmation *(Please mark if you agree.)*

☐

I hereby confirm that I have read and understood this data protection/consent form and under these conditions I would like to participate voluntarily in the study within the research project "ManyFold".

2. Name, first name: _____

3. Date and signature:

C - Workshop analysis sheet

Idea ID	Use case	Data/Domain description	Type of data	Type of form and fold (Section 3)	Visualization concepts (Section 4)										View/UI distribution	Visualization Task	Key Interaction	Ways to handle	Photo of prototype
					More Displays: Multiple Views	More Displays: UI Offloading	More Displays: Detail-and-Overview	More Displays: Structural Alignment	More Shapes: Spatialized Views	More Interaction: Exploration	More Interaction: Slice & Filter	More Interaction: Comparison	More States: Reconfiguration & User Goal	More States: Device Role & Collaboration					
I1	Emergency Medical Notebook	Medical record, health data, task reminders, environmental alerts	Temporal data, multivariate data		X	X				X	X			X	* static/specific assignments of views and panels (booklet) * UI distribution responsive to the folded states - cube vs. docked display vs. flat display shows different UIs and applications * different screens for different details	* outside kind of public screen/information, inside then details for personal purpose and doctors * time-based visualizations but also event visualization, multivariate	* page flipping for switching between views	* handheld or hang in front of body	
I2	Transformable Cube	Health data	Multivariate data				X		X				X	X	* responsive UI reconfiguration across three states: horizontal, vertical and circular	* overview+detail based on folded states: cube shows overview and unfolded shapes show details * Compare (left and right) data views between different screens (in docked mode)	* when it's docked, utilize touch (panning and zooming), physical folding angles, and air gestures or eye-tracking to navigate the data * use hinge angle for zooming	* both handheld and surface-supported (in cube or docked states)	
I3	Animal Health Monitor	Health data (spine graph, heart rate graph, table...)	Multivariate data		X		X			X		X	X		* responsive UI reconfiguration across three states: horizontal, vertical and circular	* show different data in different foot states: horizontal shows geographic data, circular wrapped around animal leg shows bio-sensed data * display shopping list if used by human	* Automatic switching UI configuration when fold state changes * "slide" or "grab" visualizations to move them between different physical panels (channels) for comparison.	* worn on body if circular, otherwise held in hand like a map	
I4	Connected Circular Displays	Health data Mood or nutrition information	Multivariate data		X		X							X	* double-sized display with multiple views, displays on all sides	* when folded the outside displays overview and inside shows another encode of the data * change color to show the emotion of the person eg. elderly * alternative views on opposite displays, or filter based on selection on other/previous display * fisheye view (focus+context) on inner displays	* pan and zoom on the outside of the device, unfold it to see selected view of the focused area * flip device (in minimal footprint) to show data in different encoding or to show data filtered according to selection * back-device interaction in max. footprint state (e.g. panning) * use device as a lens (2nd device above a bigger screen)	* mainly handheld, could be wearable	
I5	Foldable Map Device (Nintendo Switch-Inspired)	Geographic data (country/region selection, heat maps, satellite/navigation views)	Temporal data, spatial data		X	X				X		X			* UI offloading - two smaller displays on the left-right sides have joysticks * Unfold left-right to add controls, unfold up-down to add view or screen size * Distinct data view and control/UI view	* Inspired by game controller, they designed joysticks on left and right screens for navigating spatial-temporal data * two views (up and down) for comparison, one a heat map and another a satellite	* mimic form and interaction of mobile gaming console (Nintendo Switch) * angle between displays affects view arrangement/size (two views vs one stretched view when fold angle above 135 degree)	* handheld when folded, surface supported when unfolded	
I6	Triangular Modular Display (Tessellation Concept)	Domain-agnostic	Quantitative data						X	X					* triangular displays composing a shape-changing device * no explicit info about the UI or view	* overview of data by looking and feeling the display shape (any quantitative data)	* user shapes the device form arbitrarily	* flexible to be folded into any shape so it can be rollable, wearable or stand in environment	
I7	Smart Glasses with Adjustable Foldable Display	Time, notifications, health data	Multivariate data			X								X	* information can be displayed on the stripes of the panels * mentioned something like an external display	* additional views (augmented, situated) * information, monitoring guide navigation (like automotive navigation system)	* change color of the panels with fold angle * fold panels to activate or deactivate additional views (blend in/out) within field of view of a user (like with MR-headsets) * touch in stripes of the panels	* wear like glasses	
I8	Foldable Watch with Extending Strap Display	Health data	Multivariate data			X	X			X					* menu offloaded to the watch strap	* visualize data on straps that fit more the shape of the display * overview+detail	* open/unfold to see details (details on the inside)	* wearable	
I9	T-Shaped Foldable Comparison Device	Product data, attribute comparison	Multivariate data		X		X					X			* displays show different objects with parameters to compare * only 1-side display (big), 2-side for smaller display	* overview+detail, one merged view show a figure with all data points while two views show details of two individual data points * multicoordinate view with one update affecting another view * visual comparison * correlation view inside * linked brushing	* mainly touch interaction as on smartphones * unfold for additional view * hinges would stay/nap at certain angles	* lay on table or handheld	
I10	2-panel foldable device with three distinct states: completely folded, partially opened (90 degrees), and completely laid out flat	Sales and stock data	Multivariate data, temporal data		X		X						X		* 3 folding states showing different levels of details of a data set * replication of views (outside view also visible inside)	* overview+detail, one merged view show a figure with all data points while two views show details of two individual data points * min. footprint is overview dashboard * overview and details with small multiples	* folded to show overview, unfolding reveals additional layers * mode switch: fold angle determines view/layout (half-open for dashboard + details, fully-open/flat for small multiples) * changes in one view affects other views	* handheld like a foldable phone	
I11	Foldable Wearable with Rolling/Sequential Expansion	Activity data	Multivariate data, temporal data		X							X			* extended view when unfolded * one 2-sided screen, others are 1-sided	* folded state shows overview, unfolded state shows detailed view * numerical, glanceable view in min. footprint, visual view in max. footprint * different data aggregation levels	* spatial hand gesture (twisting, similar to how you activate a smartwatch display) to switch between data attributes for chart * common touch interaction (e.g. for changing data aggregation)	* wearable	
I12	Separable Screens for Decoupling Overlaid Visualizations	time-based health data (e.g., steps tracked over days of the week)	Temporal data, periodic data (temporal)		X		X					X			* individual display panels per time frame	* temporal/time-dependent data * data aggregation configurable (daily, monthly, ...) * comparison of views	* Unfolding to bring cluttered or overlaid view into separate panels	* wearable bracelet or watch	
I13	Overview+Detail with Separate Displays	Health data	Multivariate data		X		X					X			* alternative/detailed view when unfolded	* details on demand for part of data (on user interest)	* unfold part of device (non-linear)	* handheld, smartphone-like	
I14	Triangular Modular Display for 3D Data Physicalization	Abstract data represented by shape, such as a map with house prices.	Spatial data						X	X					* the surface is the visualization and UI at the same time	* surface visualization (sci-vis)	* no real folding but related * can be actuated, automatic shape change	* can be passive (no interaction) or active (manipulate data/values) by changing shape	
I15	Accordian Fold for Comparison and Filtering	Comparative data sets (not further specified)	Multivariate data		X							X			* each panel same visual encoding (small multiples) * panels relatively individual	* small multiples * visual comparison	* fold to bring views closer (side-by-side, juxtaposed)	* surface-supported accordian display	
I16	Layered Data Navigation via Tiling	Patient/health data, volumetric data of human anatomy	Layered data				X			X	X	X			* smaller side display foldable to control the main display	* layers of human anatomy showing different views * overview+detail approach	* quick/short fold-gestures (up and then down) of the detail view/panel for selecting the layer/view of the overview	* handheld	
I17	Perspective Wall with Multiple Focus Areas	Domain-agnostic (technique focused)					X			X					* not explicated	* perspective wall (focus+context) showing multiple focus areas of the same data	* multiple side-panels that could be unfolded on-demand	* handheld	
I18	Two Connected Circular Displays (Educational Data Subunits)	Entity information with attributes, student details, school kids (performance)	Multivariate data		X		X	X		X		X			* folded outside overview, unfolded inside showing individual student's data for comparison * visual comparison (school-kid, kid-kid, school-school) * outside view in min. footprint shows all the data (overview) * overview+detail, select one stock to show more information on the 3rd screen	* turning any panel (quick flip gesture, not folding) to browse through lists * touch interaction * interesting hinge concept: one-point hinge can not just be folded but also be turned towards and away from the viewer			
I19	Three Rectangular Screens for Stock Market Analysis	Stock data	Temporal data, multivariate data		X		X								* 3 inside displays in max. footprint, 1 outside display for min. footprint	* 2x overview+detail in each other: panel 1 = overview, panel 2 = detail, panel 3 = detail of panel 2	* touch for selection, then details on other panel * fold together for overview	* handheld	

D - Demographic questionnaire

Date:

ManyFold Questionnaire

What is your age (in years)? ☐ Please specify:
☐ Prefer not to answer

What is your gender? ☐ Woman ☐ Man ☐ Non-binary ☐ Prefer not to disclose
☐ Prefer to self-describe:

Which academic degree are you currently pursuing? ☐ Bachelor ☐ Master ☐ PhD ☐ Other:
☐ Prefer not to answer

How do you rate your experience/expertise on the topic of **data visualization**?
☐ Beginner ☐ Novice ☐ Intermediate ☐ Advanced ☐ Expert ☐ Prefer not to answer

How did you acquire your knowledge on **data visualization**?
(multiple answers allowed) ☐ Lecture/Exercise ☐ Workshop/Seminar
☐ Professional activities (e.g., job)
☐ Other:

How do you rate your experience/expertise on the topic of **human-computer interaction**?
☐ Beginner ☐ Novice ☐ Intermediate ☐ Advanced ☐ Expert ☐ Prefer not to answer

How did you acquire your knowledge on **human-computer interaction**?
(multiple answers allowed) ☐ Lecture/Exercise ☐ Workshop/Seminar
☐ Professional activities (e.g., job)
☐ Other:

How often do you use a foldable phone or similar device (not a notebook/laptop)?
☐ Never, not at all ☐ Rarely (tried it out) ☐ Less than once a month ☐ Weekly ☐ Daily ☐ Prefer not to answer

How do you rate your experience/expertise in **Origami** and similar paper folding techniques?
☐ Beginner ☐ Novice ☐ Intermediate ☐ Advanced ☐ Expert ☐ Prefer not to answer

Experience / Expertise Values

Beginner	<i>I have little to no knowledge or experience with this.</i>
Novice	<i>I have some basic knowledge and understanding of this, but I'm still learning and need more practice.</i>
Intermediate	<i>I have a good understanding of this and can apply it in some situations, but I may not be familiar with all aspects.</i>
Advanced	<i>I have a strong understanding of this and can apply it in most situations.</i>
Expert	<i>I have an in-depth understanding of this and can apply it in all situations.</i>

E - Data from the demographic questionnaire

PUID	AGE	GENDER	ACAD_DEG_PURSUIING	DATAVIS_EXP	DATAVIS_EXP_VERB	DATAVIS_EXP_HOW	HCI_EXP	HCI_EXP_VERB	HCI_EXP_HOW	FREQ_USE_FOLDABLES	FREQ_USE_FOLDABLES_VERB	ORIGAMI_EXP	ORIGAMI_EXP_VERB
01w1	26	Man	Master	4	Advanced	Lecture/Exercise, prof. Activities	3	Intermediate	Lecture/Exercise, Workshop/Seminar	2	Rarely (tried it out)	2	Novice
02w1	25	Man	Master	3	Intermediate	Lecture/Exercise, Workshop/Seminar	3	Intermediate	Lecture/Exercise, Workshop/Seminar	2	Rarely (tried it out)	2	Novice
03w1	25	Man	Master	2	Novice	Lecture/Exercise	3	Intermediate	Lecture/Exercise	2	Rarely (tried it out)	3	Intermediate
04w1	21	Prefer not to disclose	Bachelor	3	Intermediate	Lecture/Exercise	2	Novice	Other none	1	Never, not at all	1	Beginner
05w1	24	Man	Master	-1	Prefer not to answer	Workshop/Seminar	1	Beginner	Workshop/Seminar	2	Rarely (tried it out)	2	Novice
06w1	26	Man	Master	3	Intermediate	Lecture/Exercise	3	Intermediate	Workshop/Seminar	2	Rarely (tried it out)	2	Novice
07w1	26	Women	Master	4	Advanced	Lecture/Exercise, Workshop/Seminar, prof. Activities	3	Intermediate	Workshop/Seminar, prof. Activities	2	Rarely (tried it out)	5	Expert
08w1	25	Women	Master	3	Intermediate	Lecture/Exercise	3	Intermediate	Lecture/Exercise, prof. Activities	2	Rarely (tried it out)	1	Beginner
01w2	26	Man	Master	3	Intermediate	Lecture/Exercise	3	Intermediate	Lecture/Exercise	1	Never, not at all	1	Beginner
02w2	23	Women	Bachelor	3	Intermediate	Lecture/Exercise	2	Novice	Lecture/Exercise	1	Never, not at all	1	Beginner
03w2	24	Women	Master	3	Intermediate	Lecture/Exercise	2	Novice	Lecture/Exercise	2	Rarely (tried it out)	2	Novice
04w2	25	Man	Master	3	Intermediate	Lecture/Exercise	2	Novice	Lecture/Exercise	2	Rarely (tried it out)	2	Novice
05w2	25	Women	Master	2	Novice	Lecture/Exercise	2	Novice	None	2	Rarely (tried it out)	1	Beginner
06w2	30	Man	Master	3	Intermediate	Lecture/Exercise, prof. Activities	4	Advanced	prof. Activities	2	Rarely (tried it out)	1	Beginner
07w2	Prefer not to answer	Women	-1	1	Beginner	Lecture/Exercise	1	Beginner	Lecture/Exercise	1	Never, not at all	2	Novice

F - Sketching sheet

Name / Title of the Concept		Date	Version 2	
Sketch(es) of the Concept			Usage location / scenario	
			Function / Purpose	
			Vis technique	
			Data (type, source)	
User Interactions				
Foldable States (Constellations)			Shape	

G - Pre-cut cardboard shapes in different shapes and sizes



H - Workshop setup with materials for one of the student groups



I - Impressions from the ideation workshop



