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Visualization of Complex Familial and Social Structures

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Abstract

Visualizations are widely used when working with family and genealogical structures, both to navigate through the generations and to provide overview information about the family as a whole. Our research investigates the concept of "marriage" in the complex and polygamous familial structures of Mormon society in mid-1800s Nauvoo, IL, including several definitions of marital and relational ties. We have found current visualizations to be insufficient in fully expressing this complexity.

We present visualizations based on chord and flow diagrams to capture the locality and cohesiveness of larger and more complex family units and encapsulate familial dynamics into the nodes of their overall lineage. Each family unit is portrayed as a chord diagram adapted to display intra-familial relationships with a left-to-right generational flow and chords indicating relationships between participants. Zooming out, we depict the overall lineage as a modified flow diagram with the family units as nodes, connected with others based on the participants; each hyper-edge links an individual's family of birth to her adult marriage.

Our implementation has yielded evocative and provocative visualizations–preserving locality of family unit members, an overall temporal order on their display, and distinguishability of relational types–by which scholars can investigate these complex social structure.

Introduction

Our research in familial structures focuses on investigating the concept of "marriage" in early Mormonism. In the mid-1800s, in Nauvoo, Illinois, the Mormons expanded and redefined their concept of marriage, including polygamous unions and multiple definitions of marital and relational ties. Through this motivating application, the *Nauvoo Marriage Project*, we are attempting to discover and depict the familial and lineage structures and their relationship to the ecclesiastical structure of the time. Using large-scale depictions of the social structures created by these marriages, we seek to make susceptible to analysis their intent and social significance. The objects of study in this research are the relationships people form at many different levels: parent/child, spouse/spouse, individual/family unit, family unit/family unit, individual/group, and group/group.

To begin to understand and analyze these complex familial ties and lineages, we explored an array of visualization techniques for depicting family and genealogical structures and social networks [1–4, 6, 9–11, 17, 18, 21, 23, 25, 26]. It was imperative to the historian that we express the family unit and its participants as a cohesive group, maintain a temporal ordering of events, and produce a depiction in which the persons and various relationship types are quickly discernible. We found that current visualization techniques are insufficient to fully express the level of complexity found in our familial structures.

In this paper, we first discuss our motivating application, the Nauvoo Marriage Project and related genealogical visualizations. We then outline our visualization approaches to family units and their larger lineage contexts, including extensions to those approaches. We conclude with our implementation and evaluation with respect to the Nauvoo Marriage Project and future work.

Nauvoo Marriage Project

The Nauvoo Marriage Project, led by Dr. Flake, seeks to investigate and understand the concept of "marriage" in early Mormonism. In the mid-1800s, Nauvoo, Illinois, early Mormons began to re-define marriage, in a way that is still not fully understood by scholars. Individuals participated in both polygynous and polyandrous marriages to create desired family units, kinship structures, and religious lineages. Our dataset evidences multiple types of marital attachment: traditional civil marriages recognized by the government; and religious "sealings" including "eternal" sealings which were believed to persist past death, "temporal" sealings which were believed to last only during life (i.e. "until death do us part"), and posthumous eternal sealings performed by proxy. Each of these types of marriage has its own significance, but understanding their use and interconnectedness among family units and across generations is key to uncovering the social constructs the early Mormons were creating.

Adding to the complexity of the dataset, the construction of the Mormon temple in 1845 played an integral role, as marriages and "sealings" were repeated in the temple. Parent-child relationships also gained religious significance during this time. Children born before the temple was built were "adopted" to their birth parents in the temple to connect them under this new kinship and religious lineage network. Continuing this trend forward, some mothers are sealed to their daughter's husbands, aunts are maritally attached to their nephews, and brothers or sisters are joined with their siblings' family units.

Our dataset consists of over 70,000 individuals with numerous polygynous and polyandrous marriages. Those marriages include 5,318 civil marriages, 2,923 "eternal" sealings, and 187 "temporal" sealings. One man, the founder Joseph Smith, has 93 marital events in our database. Another 64 men have ten or more marital attachments each and 3,123 have at least two. Two women in our dataset have 8 marital events, while 2,744 have at least two. Adequately visualizing these familial, kinship, and lineage structures and the connections between them are important to begin to uncover and understand the concepts of marriage and kinship being defined and redefined in their culture. Although polygamy appears in many cultures, to the best of our knowledge there has never been a study on the visualization of the polygamous extended-nuclear "family unit."

Related Work

Visualizing traditional lineages and familial structures is a well-studied problem [2, 6, 10, 17, 21, 23, 25]. Early attempts, such

as traditional family trees, while useful to record historical genealogical data, fail to evidence details of more complex marital structures, including marriages with more than two spouses. Figure 1a depicts a traditional representation of Parley Pratt's family unit consisting of 13 parents and 16 children. As more spouses and children are added, for example Brigham Young's family unit shown in Figure 1b, the diagram expands to become unreadable. This visualization breaks a few guiding principles for family unit depictions: the depiction should maintain a temporal ordering (*temporality*), participants should be displayed together as a unit (*locality*), and the types of spousal and parental relationships should be quickly discernible (*distinguishability*). Even though order can be maintained in the spousal relationships, maintaining temporal order in the children would further complicate the visualization. Likewise, the children in this diagram visually separate the spouses because of their parental connections, giving a false impression of timespan between marriages. We therefore highlight a few recent related works which seek to address similar more complex genealogies and to capture the temporal nature of family units.

GeneaQuilts [6], was created by Bezerianos, et al, to display large-scale genealogies of thousands of individuals. Individuals from each generation are listed, connected by grids that match parents from the previous generation to children in the subsequent generation. The visualization flows from left to right through the generations. GeneaQuilts achieves *locality* only in small cases, but it fails to provide *temporality*. The authors employ an intra-generational layout algorithm that favors grouping siblings of the same biological parents, which provides *locality*. As the number of parents in the same generation increase, parents and children are spread farther apart in the display, reducing *locality*. An attempt to introduce *temporality* by replacing the layout algorithm with one ordering participants temporally would require sorting by birth date and marriage date simultaneously, since parents and their siblings are shown in the same genealogical level.

In contrast, Kim, et al [17], created the TimeNet visualization for genealogical data to better address and visualize each family unit's temporal relationships. Their visualization focuses on a time-line of individuals' lives as a line from their birth to their death. When individuals marry, their time-lines converge to a horizontal axis; when they divorce, their time-lines bifurcate. Additional spouses are depicted as additional converging time-lines to the "cluster" of individuals in the shared relationship. Children are depicted with their own time-lines connected to their parents by a vertical dashed line. Since their work focuses heavily on visualizing the temporal nature of the lineages, it prioritizes this over capturing internal relationships between participants of one family unit, including those in which multiple spouses and children are involved. As individuals divorce and marry, the diagram becomes more visually complicated and nuclear family units are spread farther apart. The authors make the choice to exhibit *temporality* at the cost of *locality* and *distinguishability*.

Ball and Cook [2] define a similar time-line-based visualization scheme to address the connection of individuals in a common family unit. Their work depicts time vertically, with individuals as time-lines from their birth to death; however they visually group children of the same binary, (i.e. husband and wife), marriage. A box is drawn around these children, with the top of the box denoting the marriage date of their parents and the bottom denoting the death date of the last remaining child. Parents of the marriage are depicted as small boxes above the bounding box, and a connecting line drawn from a parent to their actual time-line depicted within the marriage into which they were born. While Ball and Cook's visualization exhibits the same overall *temporality* as Kim, et al, it better visually collects binary family units, increasing its *locality*. Their visualization's attempt to provide *locality* fails when considering marriages consisting of more than two spouses.

While both Kim and Ball's work attempt to better visualize the temporal aspects of individual family units (*temporality*), all three fail to fully capture the internal dynamics and relationships within the families (*locality*). Scaling or extending these methods for complex families such as polygamous units would degrade *distinguishability* among the visualizations. Our approach attempts to capture and visualize the temporal aspects of family units, similar to Kim and Ball, while at the same time maintaining family unit cohesiveness and providing a depiction of the larger genealogical flow and its evolution.

Visualizing Family Units: Chords

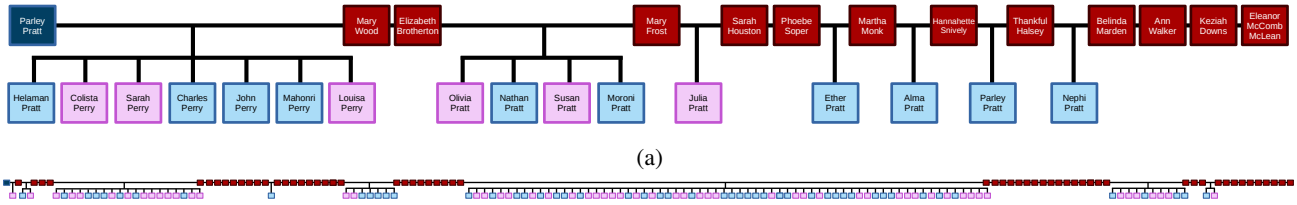
The participants and relationships within a family unit are often depicted as a standard directed graph—a node for each participant and an edge for each relationship between two participants [21]. The creation of such depictions immediately faces the question of "layout," to best depict locality and cohesiveness among members. A chord diagram [14, 16, 18, 19, 24] partially answers the layout question by representing each participant as a section of the circumference of a circle. This is only a partial answer to the layout question because the order of the participants around the circle and the size of the circumference section for each still need to be specified. By displaying the family unit as a circle, we embed the concept of a "nuclear family unit" into the visualization; a concept that is not found in the traditional family trees, such as those depicted in Figure 1. The relationships are then edges connecting two points on the circle, passing through the interior of the circle, namely "chords" of the circle, hence the name, "chord diagram."

We adapt the chord diagrams to cover familial structures' temporal nature by imposing a generational structure on the participant layout. Participants in the family unit are depicted as sections of the circumference with adult participants along the left semi-circle and with children and adoptees along the right semi-circle. This layout then produces a left-to-right flow of the lineage and generation[1].

The relationships between participants, including spouse/spouse and parent/child relationships, are depicted as the chords. To include an additional overall temporal aspect to the diagram, participants are arranged in chronological order from top to bottom, such that newer members of the family unit, in either generation, are drawn closer to the bottom.

Figure 2 visualizes a straight-forward family unit consisting of two parents and six children. Here, red and blue depict the gender of the participants and the chord colors depict the different types of relationships present. Green represents a biological child relationship, while pink and purple denote two different types of marital relationship. As more participants enter the family unit,

[1]The choice of left-to-right is inspired by time-lines; genealogy visualizations of all orientations are common in tools today.



(a)

(b)

Figure 1. *Traditional family tree depictions for (a) Parley Pratt and (b) Brigham Young, similar to the design of Family Echo's layout, `http://familyecho.com`. Spouses are shown in order, left-to-right, but the spacing with children produces a false sense of time across the visualization. Similarly, overall child ordering is not depicted. Including ancestors for the parents will combine these two trees, decreasing their legibility, since Pratt and Young married two sets of sisters.*

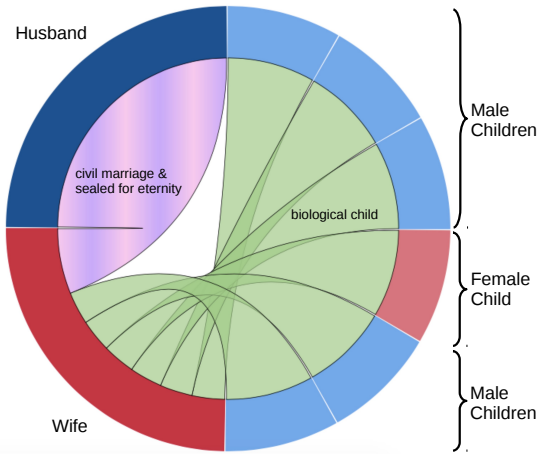


Figure 2. *Family unit visualization displaying two parents and six children, anotated for clarity. The chord connecting the husband (top-left) and wife (bottom-left) denote their multiple relationships (pink and purple). The chords connecting the wife to the children denote a biological (green) relationship between them. To simplify the diagram, we do not also connect the children to the husband.*

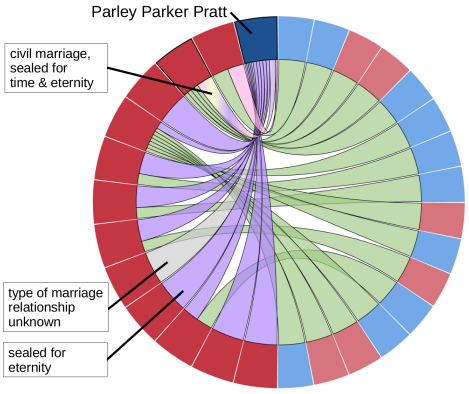


Figure 3. *Parley Pratt's family unit depicted using our modified chord diagram, showing his 12 wives and 16 biological children. He was civilly married (pink) to his first wife and participated in three distinct spousal relationships with his second wife: civil marriage (pink), sealed for time and eternity (yellow and purple). With most of his other wives, he was sealed for eternity.*

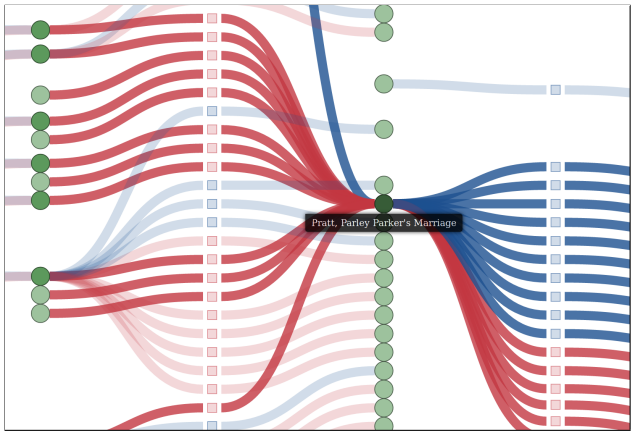


Figure 4. *A subset of Parley Pratt's lineage as depicted in the lineage flow diagram. His family unit and its participants are highlighted. Parental figures flow into the left of the family unit node (dark green); children flow out to the right.*

the expressiveness of the diagram becomes increasingly important. Figure 3 depicts Parley Pratt's family unit with 13 parents, 3 types of marital connections, and 16 children.

Because the complexity of the diagram increases with the number of participants, we make conceptualization decisions to maintain readability. The family unit is depicted from the perspective of one member, the *primary participant*, who is always drawn as the top-left parent of the diagram. In Figures 2 and 3, both of these individuals are patriarchs, i.e. the diagrams are shown from the husband's point-of-view. For our research, we assume that children are connected to two parents, the primary participant and another spouse. Therefore, parental relationships, either biological birth or adoption, are only connected to the spouses of the primary participant. This is a simplification on our part, due to our motivating application. The diagram could be extended to display step-children and children born to the spouses before they were married using a secondary chord color scheme or by connecting the children to each of their birth parents.

Visualizing Lineages: Lineage Flow

We approached the problem of connecting family unit diagrams by considering Sankey [22] diagrams. These diagrams can be used to convey both flow and geo-spatial information. Our primary interest is in the former, therefore we originally considered more simplified flow diagrams [13, p. 153–158], which consist of directed graphs where all edges "flow" in a particular direction. Lineages have this inherent "flowing" nature, directed from an-

cestors to descendants. Specifically, when considering lineages, we note that the flow is verbalized as individuals flowing from the marriage of their parents to their marriages as adults, then their children flowing to the next generation, and so on. Therefore, we conceptualize this network with family units as nodes and the individuals as the directed edges from their birth to adult families.

Under this conceptualization, we create *lineage flow diagrams* that join individual family units into a comprehensive ancestral network: an identifiable family at each node connected with edges being the people that constitute the participants. This diagram depicts male participants as blue edges and females as red edges. The individuals then connect, in a directed left-to-right flow, the family unit of their birth to their own marriages as an adult, exampled in Figure 5. As individuals connect to multiple adult spouses, their edges conceptually bifurcate to connect to all adult family units. Since hyper-edges are difficult to portray, we instead depict the lineage flow as a bipartite graph with small boxes at the bifurcation points. This tweak provides the historian with a definitive point to examine along the edge for identification. Figure 6 shows Catherine Kremer's two connections to John Bernhisel's father as well as Bernhisel himself.

We utilize the Sankey diagram's spatial properties to convey generational information, similar to the method employed by Cui, et al [8], in TextFlow's topic flow visualization. As they depicted time on the x-axis, we align our family units temporally into relative generations from left-to-right. In general, and for straightforward lineages, this relative generational layout will directly correlate to actual generations. In Figure 5, we see four generations of Zina Huntington's lineage. Her and her husbands' grandparents' family units align on the far left, the family units of both her and her husbands' parents align in the second vertical generation, her family unit and those of her siblings align in the third vertical generation, and finally those of her children on the far right. Spatial irregularities in a lineage depicted in this way alert the researcher to cases where further investigation is needed. Cross-generational connections when family units are depicted in their correct relative generation, as seen in Figure 6, indicate that an individual married someone of an earlier generation (e.g., a parental figure). Conversely, if an individual's family unit is depicted in a subsequent (i.e. later) generation from their temporal peers, it likely means they married a peer's child. In either case, these irregularities evidence important changes to the kinship line to be investigated.

Extensions

We extend these visualization techniques to provide our historians with access to more fine-grained facets in the data. By employing a consistent and distinct use of color, refining data focus through mouseovers, and providing temporal filters using time sliders, the historian can quickly gain an overview depiction of the families and linages while exploring in greater detail how relationships and family units evolve.

Use of Color

We use colors to increase the *distinguishability* in our visualizations. In order to depict the multiple relationship types needed for our complex familial structures, we chose a distinct color palette to disseminate the information on first glance. Table 1 provides our full use of color.

Color palette for visualizations

Color	Definition
red/pink	Female individual
blue	Male individual
purple	"Eternal" sealing
yellow	"Temporal" sealing
light pink	Civil marriage
light gray	Unknown marriage type
gold	Adopted child-parent relationship
light green	Biological child-parent relationship (chord diagram)
dark green	Family unit (lineage flow diagram)

During our prototype and design phase, we tested out various neutral colors to denote gender, but found that the historian had difficulty reading the diagrams without heavily relying on the color legend. Therefore, we chose traditional gender colors, red/pink and blue, to provide a more instinctive differentiation. In the chord diagrams, we darken the parental participant colors to better distinguish them visually from their children.

Relationship types, also differentiated by color, are independent of one another but may be adjacent or overlap on the visualization. We opted for distinct colors to provide *distinguishability* between them. In certain cases, such as the husband-wife relation back in Figure 2, we utilize a repeating gradient to denote multiple relationship types rather than increasing the number of connecting chords.

Mouseover Focus

To expose more detailed information about the individuals and family units, we use the mouse as an analogue for the historian's focus. By hovering over a specific person or relationship in our family unit visualization, as shown in Figure 7, other relationships are shaded to highlight only those connected to the one under observation. In this screenshot, the historian is highlighting Mary Ann Frost to feature her four children and multiple relationships with her husband. When more information is known about a relationship, such as marriage or divorce dates, we provide those details in a "more information" box on mouseover.

By providing this functionality to the historian, we maintain *locality* of the participants in the display while increasing the amount of detail available.

Time Sliders

Since families and lineages are evolving networks [15], as new individuals get married into the family or children are born and adopted, we provide time sliders to allow the historian to view the changes in these networks over time.

Internal familial relationships may also change as the family adapts to these new individuals. Therefore, we may use our chord diagrams to depict the state of the family unit at a particular point in time and consider the diagram to evolve with the family unit. We provide a time-line and "time slider," as seen in Figure 7, to allow historians to navigate through the internal dynamics of the family unit over its lifetime, beginning when the first parents get married and continuing until the last child passes away. Fig-

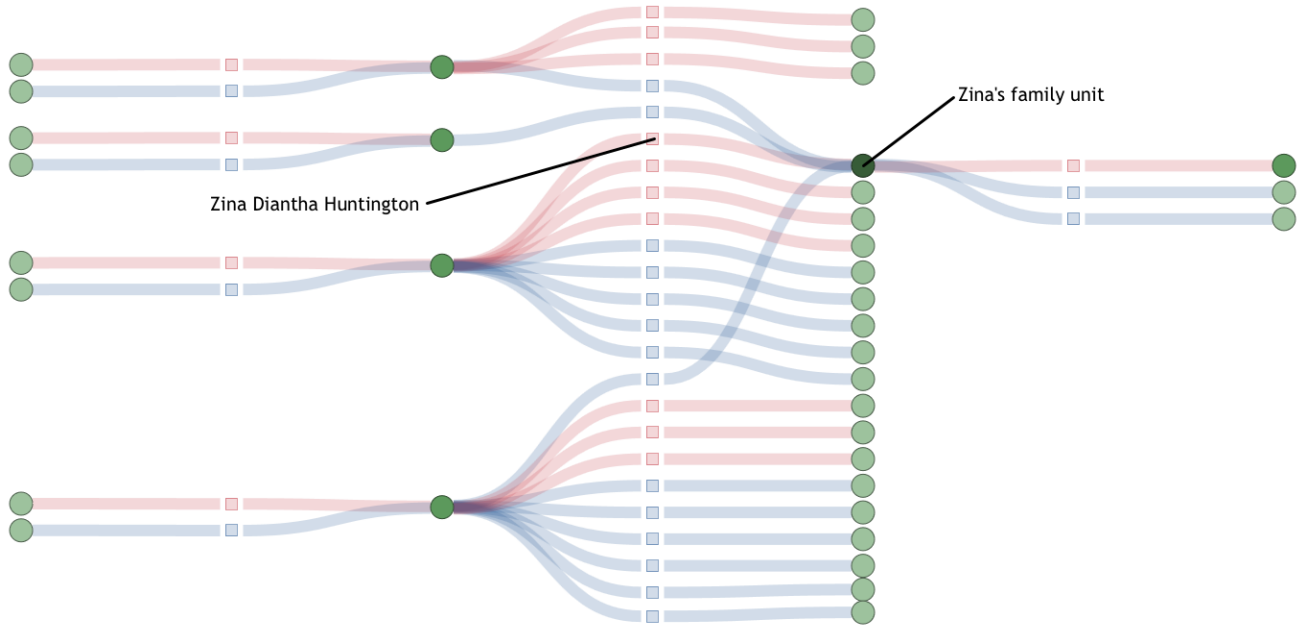


Figure 5. *The lineage flow diagram from a matriarchal perspective, depicting family units and individuals one generational level from Zina Huntington. Men are depicted as blue edges, women as red edges. The green circles are family units and are arranged in four columns. The edges connecting circles in the leftmost column to circles in the second column are people in the generation of Zina's parents. The ones connecting the second and third columns are people in Zina's generation, and those connecting to the rightmost column are Zina's children. Here we can see three husbands connected with Zina's matriarchal family unit.*

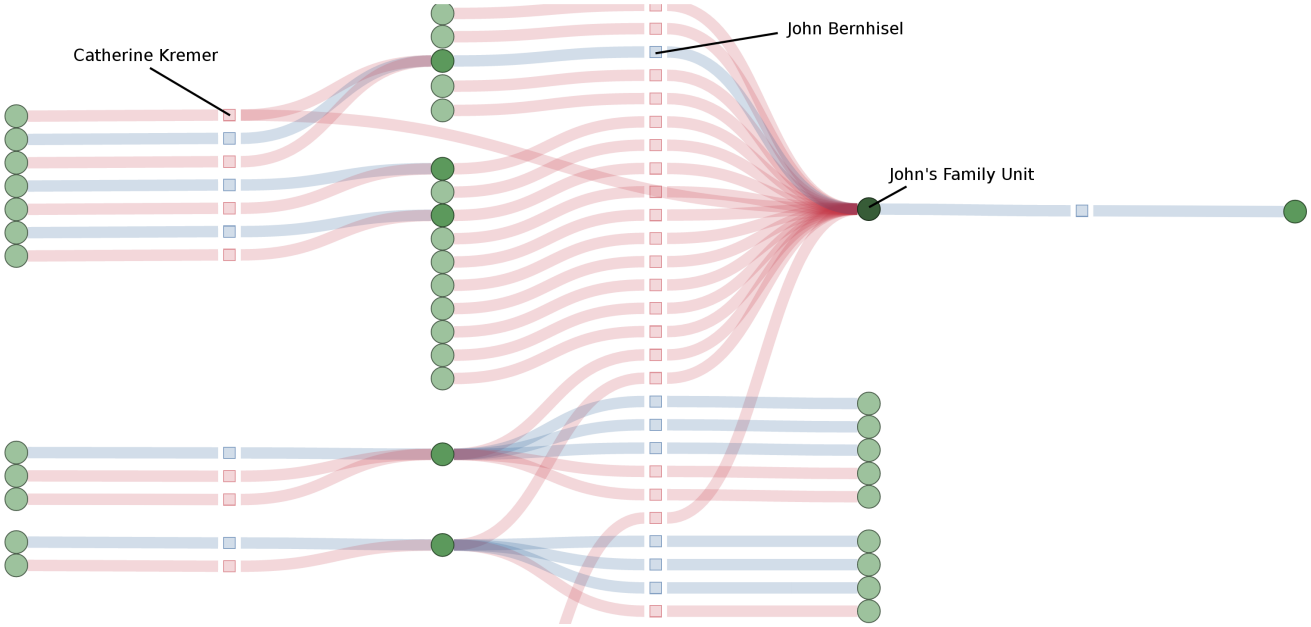


Figure 6. *This patriarchal lineage flow diagram depicts the individuals one generational level removed from John Bernhisel. It depicts a cross-generational plural marriage of Catherine Kremer to the family units of both John Bernhisel and his father, who both were sealed to multiple spouses.*

ure 8 shows the historian stepping through another family unit, that of Alpheus Cutler, over four different time points. Conceptually, each of these chord diagrams would constitute a slice of a spatio-temporal 3D chord cylinder depicting the overall evolution of the family. However, meaningfully representing and navigating such a diagram is difficult, leading us to focus on our time-line visualization.

By adding the time slider to our lineage flow diagrams, we evidence two dimensions of time. First is the who-beget-whom, left-to-right flow that is inherent in the diagram. Second is the "wall-clock" time evidenced by animation under the time slider interaction. This is a hybrid approach according to Beck, et al [5],

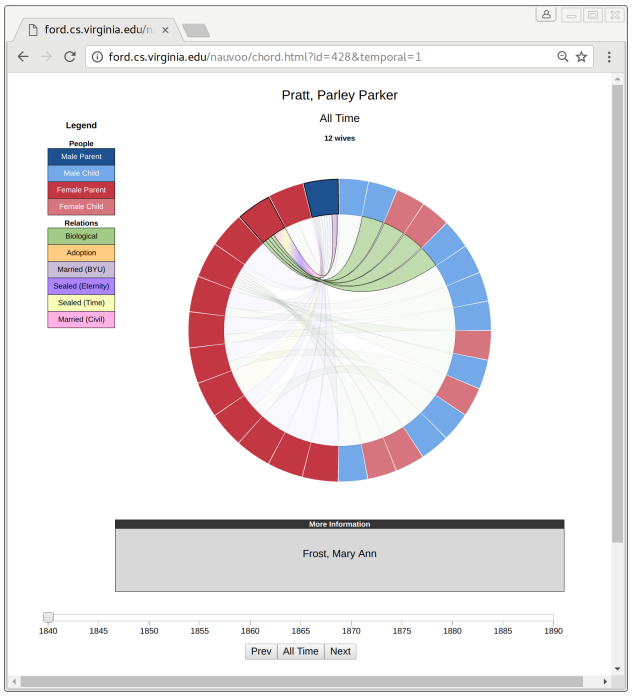


Figure 7. *Chord diagram visualization interface. Hovering over the participants or relationship chords provide more information in the box below the diagram. Here, the researcher is choosing to inspect Mary Ann Frost and her connections to Parley Pratt and her four biological children.*

and Hadlak, et al [12], combining an integrated network time-line (time as the base representation) with user-driven animation. It therefore allows the historian to both get a glance of the entire lineage and see the lineage progress as time passes, highlighting anomalies in the relative generational layout of the diagram. As the slider is moved, all individuals and marriages of the lineage flow diagram not present during the time chosen are shaded from view, highlighting the "current" picture of the lineage. Spouses that were born but not yet married are depicted as partial, disconnected edges until being connected to their adult family units on their marriage dates. Likewise, they are disconnected from those family units on divorce before being completely hidden from view on death dates. Even though we saw back in Figure 5 that Zina had three husbands in her lineage, stepping through time in Figure 9c-d we note that she only had two living husbands simultaneously, marrying both Joseph Smith and Henry Jacobs in 1842 before having her first child. Examining the temporal aspects of Figure 6 shows that Kremer's spousal attachment to John Bernhisel's family unit does not happen within their lifetimes, indicating that it is a posthumous marital sealing for kinship purposes.

Evaluation

We implemented our visualizations for web consumption to allow our historians the greatest access to new views of the dataset. We then captured their reactions to evaluate the usefulness of the approaches.

Implementation Details

Our implementation began with code from the D3js [7] framework. We augmented the existing chord and Sankey diagram layout engines with additional layout constraints to depict our new family and lineage flow structures. We chose a simplified interface, as seen throughout Figures 7, 8, and 9, to maintain the historian's focus on the visualization itself.

To create the lineage flow diagram interface, we adapted the D3js Sankey algorithm to depict all nodes and edges as the same size. We also modified the layout algorithm to maintain our relative generational separation, so that all family units (nodes) depicted together vertically belong to the same relative generation. An in-place family unit visualization is supplied to connect the lineage view with the intra-familial view. Upon clicking a family unit node, the historian is presented with a modal box containing a simplified chord diagram interface depicting that family unit's relationships–producing a "zooming" feature to inspect each node of the diagram.

We provide a web interface to the dataset and visualizations focused on 82 individuals central to Mormonism during the Nauvoo Temple era, available at `http://nauvoo.iath.virginia.edu/viz`. Family unit chord diagrams and lineage flows, from the point of view of each of these individuals, showcase the complex structures and dynamics of the best quality data available from the dataset. These diagrams are capable of depicting the marital relationships between Joseph Smith and his 57 wives[2] and Brigham Young and his 67 wives[3], as well as Zina Huntington and her 3 husbands[4]. Our interface allows the historian to choose "degrees of separation" from the focused individual, and is capable of visualizing multiple relative generations with hundreds of participants[5].

Reception

The usefulness of our approaches, especially the temporal versions of the visualizations, was immediately apparent. Within the first 20 minutes of examining the temporal data views, the historians were able to identify dozens of problems in the dataset that were not apparent over years of data curation. We found children sealed to the wrong parents, missing dates from our core example set, and erroneous marriages. Within that brief time, Dr. Flake remarked that this was "a marked shift in what we can do with the data:" it gives rise to questions, allowing her to do further research.

Aside from surfacing data issues, by providing this "wall-clock" view of the evolving lineage structure, we allowed the historian to see patterns in relation to their larger historical context, such as the merging of older and younger generations as part of the preparation for the westward movement of the Mormons to a more hostile environment.

Our matriarchal lineage visualizations have enabled histori-

[2]Joseph Smith's family unit and lineage visualizations are available at `http://nauvoo.iath.virginia.edu/viz?q=smith`.

[3]Brigham Young's visualizations are available at `http://nauvoo.iath.virginia.edu/viz?q=young`.

[4]Zina Huntington's visualizations are available at `http://nauvoo.iath.virginia.edu/viz?q=zina`.

[5]For the Nauvoo Marriage Project visualizations, we recommend limiting lineage flow displays to 2 "degrees of separation" which produce 5-6 relative generations.

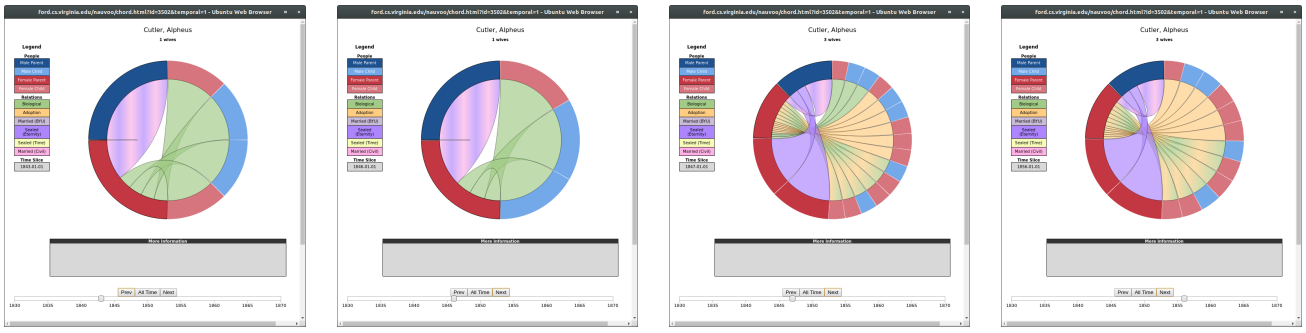


Figure 8. *Temporal interaction with the time slider at the bottom of the diagram allows the user to see how the intra-familial interactions change over time. Over the course of Alpheus Cutler's family unit, we see an initial binary marriage with four children in 1843 (a), followed by one biological child passing away in 1844, leaving three children in 1846 (b). In 1847, there are two new wives and twelve children newly adopted to the first wife (c), with the remaining biological children dying by 1856 (d).*

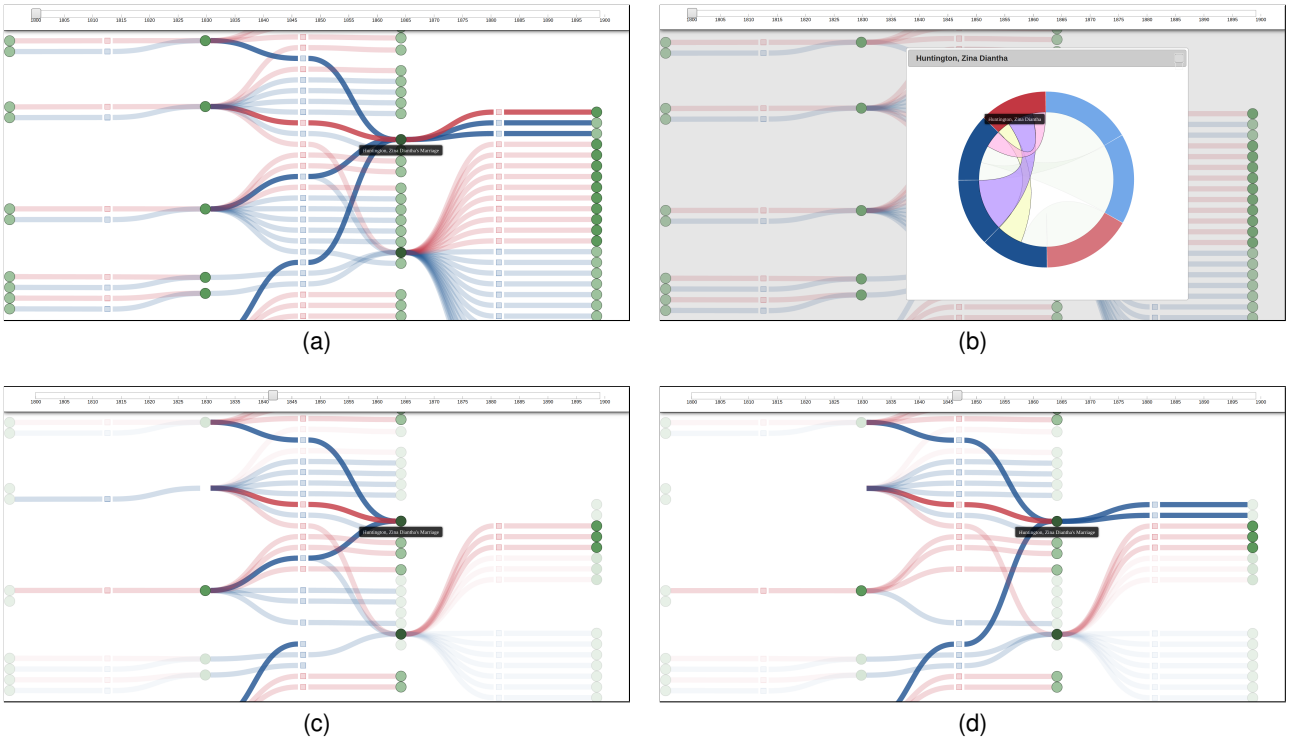


Figure 9. *The lineage flow diagram interface (a) begins by showing the entire available lineage throughout time. Zina Huntington's matriarchal family unit is shown highlighted, including more context than Figure 5. Clicking any family unit provides an in-place interactive chord diagram for that unit (b). Interacting with the time-line above the diagram shows only those individuals and family units existing during the time chosen (c, d). In 1842 (c), Zina's plural marriage to Henry Jacobs and Joseph Smith (both living) is highlighted. Brigham Young is also highlighted as a future participant, but he has not yet joined Zina's family unit. By 1847 (d), Smith has died and Zina is married to Jacobs and Young.*

ans to identify and interrogate the gendered status relationships in Mormonism's genealogical and familial structures. Particularly novel in this approach is the usefulness of these representations to enable analysis of women's liberty to marry and divorce largely at will; analysis made possible by the visualizations from a matriarchal point of view, such as Zina Huntington's shifting family unit in Figure 9. Though this marital liberty has long been known by scholars, discussion of it has been limited to anecdotal accounts. There has been no attempt to measure it on a social scale or test the anecdotal hypotheses regarding the dynamics of polyandry among Mormon polygamists or even whether these relationships should be deemed polyandrous.

Likewise, these visualizations have highlighted some of the patterns extant within the patriarchal structure. The variety of kinship ties and the sheer number of attachments in Mormon polygamous practices have frustrated efforts to arrive at defensible generalizations about the practice's nature and effects through traditional historical means of analysis. While countless claims have been made that the Mormons' iconoclastic marital system was fundamental to sophisticated political, economic, and eccle-

siastical structures, the interconnectedness (both its purposes and effects) has escaped comprehension due to its size and number of moving parts. Being able to discover through these depictions, and evidence with the temporal visualizations, the variety of posthumous or "paper" marriages to founder Joseph Smith is likely a key to understanding the dynastic forms of Mormon religious and political office and authority.

Future Work

Our future work focuses on refining our lineage flow diagrams and using the underlying kinship networks as the basis for further analytic evaluation. These lineage flow diagrams are still in their infancy: they can showcase familial interactions, cross-generational anomalies, and multiple concurrent marriages. We are considering further refinements and extensions to express more of the richness within the Nauvoo dataset. First, we will consider techniques to evidence in the lineage flow visualizations the categories of marital form (i.e. civil, "eternal," "temporal," or posthumous marriages) that are currently expressed in the chord diagrams. Likewise, we will apply techniques from the lineage flow found useful by our historians to the chord diagrams. Specifically, our historians noted that it was more apparent when children and spouses were spatially accounted for in the diagram layout, but simply hidden from view until they are born or married. Applying this technique, we will fix an individual's location in the chord layout, leaving the geometric structure of the circumference stable, while the dynamics are indicated by chords and colors coming and going through time.

A major assumption of the D3js Sankey diagram engine is that the "flow" to be displayed is acyclic. Since there are parts of the Nauvoo dataset that are not acyclic due to adoption or other inter-generational relations, we will be considering techniques to modify and extend the Sankey display to account for the exceptional connections, i.e., producing flow diagrams that maintain the relative generational flow while capturing the cycles.

In addition to increasing the amount of data provided in the diagrams, we will also investigate the user interface improvements to enable the historian easier access to that data. For example, to provide clean diagrams, identities of participants in the visualizations are currently accessible only through mouseover interactions. By providing a search interface or legend of participants that highlight relevant portions of the diagram, we may further increase the readability and *distinguishability* of the visualizations.

Lastly, as noted above, visualizations for a specific part of the Nauvoo dataset differ depending on the choice of perspective on the marital unit, such as patriarchal, matriarchal, or binary. The differences are not standard graph relationships, e.g., dual graphs. Thus, we will investigate visualizations (and analysis) to highlight differences evidenced by choice of perspective both in their entirety and as the lineage networks evolve over time.

Applications to Other Domains

We note that our visualization and network conceptualization techniques, displaying people as the edges, may be applied to other datasets containing graph-centric data, such as social-document networks, communication networks, and citation networks. In social-document networks, groups of individuals participate in shared documents. For example, the Social Networks and Archival Contexts project [20] connects identities with archival documents using "referenced in" or "creator of" links. As an application of our techniques, we may consider the documents as nodes and the authors as hyper-edges connecting from the documents they are referenced in to the documents of which they are the creators.

Similarly, we may consider citation networks, those derived from electronic paper archives such as arXiv.org. In this case, we may consider the co-authored papers as the nodes with authors as edges connecting the papers they author to those in which they are cited. Visually, we would be able to see the flow of information across articles as well as disciplines. In our Nauvoo dataset, we considered different definitions of family units: binary marriages, matriarchal, and patriarchal units. Applied to citation networks, different definitions of authorship, such as individual author, departmental affiliation, or university or institutional affiliation may be considered. Visualizing and analyzing these different authorship lineages may provide larger insights into the publication trends of departments as compared to their individual faculty members. In each of these cases, we could analyze these re-conceived networks as mentioned in our future work: evaluating centralities and connectedness as the networks evolve and papers and authors, or documents and identities, are cited or included in the graph.

Conclusion

We have adapted existing data visualization techniques, flow and chord diagrams, to produce novel conceptualizations and visualizations of genealogical and familial structures. Compared with existing techniques and best practices, our visualizations are capable of providing a rich view of kinship structure and lineage flow as well as the internal relationships and dynamics of the individual familial structures. They maintain *locality* among members of the familial units, provide an overall temporal flow (*temporality*), and allow for quick *distinguishability* between relationship types.

We implemented and applied our techniques to a complex set of families from early Mormonism in Nauvoo, IL. In our preliminary research group, we have found that the lineage flow and chord diagrams provide the researchers with evocative and provocative visual cues for relationships in the Nauvoo dataset. That includes highlighting data irregularities and patterns in the kinship structure over time, while also hinting at the larger role and freedom enjoyed by women in their marriages. While we anticipate additional refinements in diagram structure, our lineage flow visualizations are providing starting points for interesting analytic results on the underlying re-conceived network of marriage nodes and connecting individuals.

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