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CV3: Visual Exploration, Assessment, and Comparison of CVs

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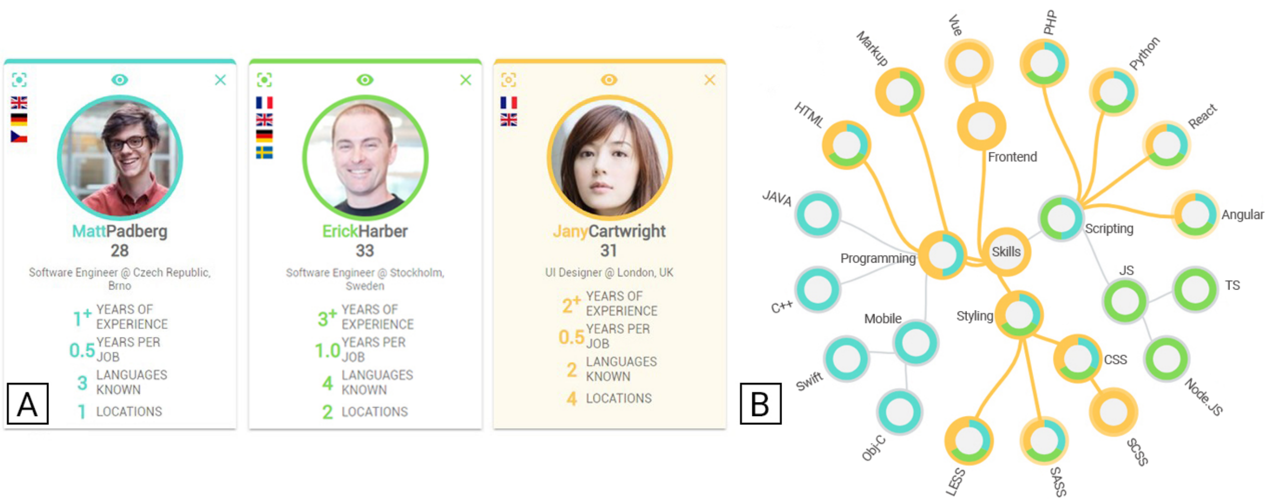

Figure 1: *Visualizations in the Compare View. Cards (A) show general information such as age, occupation, years of experience, number of languages known, mobility, and average duration per employment. The Skill tree (B) shows the selected candidates combined skill sets.*

Abstract

The Curriculum Vitae (CV, also referred to as "résumé") is an established representation of a person's academic and professional history. A typical CV is comprised of multiple sections associated with spatio-temporal, nominal, hierarchical, and ordinal data. The main task of a recruiter is, given a job application with specific requirements, to compare and assess CVs in order to build a short list of promising candidates to interview. Commonly, this is done by viewing CVs in a side-by-side fashion. This becomes challenging when comparing more than two CVs, because the reader is required to switch attention between them. Furthermore, there is no guarantee that the CVs are structured similarly, thus making the overview cluttered and significantly slowing down the comparison process. In order to address these challenges, in this paper we propose "CV3", an interactive exploration environment offering users a new way to explore, assess, and compare multiple CVs, to suggest suitable candidates for specific job requirements. We validate our system by means of domain expert feedback whose results highlight both the efficacy of our approach and its limitations. We learned that CV3 eases the overall burden of recruiters thereby assisting them in the selection process.

CCS Concepts

• ***Human-centered computing*** → ***Information visualization; Visual analytics;***

1. Introduction

In the last decade the search for employment has become more electronic - due to the increasing amount of people having access to the internet. As a result of this, a magnitude of Electronic Curriculum Vitae (E-CV) builders have been developed and provide users with the option to showcase their personal information, skill sets, and work/education histories in a clean and visually pleasing manner. Such services are offered by e.g., Represent.IO [Rep], VisualCV [Vis], EnhanCV [Enh], Vizualize.me [Viz], and DoYouBuzz [DoY]. People working as hiring managers must carry the time-consuming and non-trivial task of evaluating the different careers of candidates or employees. This includes reading through their work and education experience, assessing their skill sets and language proficiency, and understanding their career choices; all of this while extracting strengths and weaknesses out of each experience. Hiring managers can quickly navigate through and extract relevant information from a single CV, due to the fact that they are accustomed to standard résumé formats, such as EuroPass [Eur]. Once the evaluation has been done, recruiters must compare the careers of the candidates in order to build a short list of people who appear to have all the necessary skills required for the job. The most common and intuitive way to do so is to compare the CVs side-by-side and go through each of the sections individually. However, since the advent of the new E-CV trend, more employers accept CVs online via e-mail or other mediums. This inevitably led to an increased number of applicants for each position. As the number of candidates grows, recruiters need to read through and make sense of a rapidly increasing amount of résumés. As a result of this, it is more difficult to maintain a comprehensive overview. Furthermore, it is cumbersome and inefficient to compare the events across multiple CVs by navigating back and forth between them. It becomes obvious that this technique does not scale very well, thus justifying research for a new approach. To the best of our knowledge, no other system attempted at competitively ranking the candidates for a specific job application: most of them just show a list based on a user-based recommendation (see Section 2). To tackle this problem, we present CV3: an interactive environment supporting users in their tasks of exploring, comparing, ranking, and analyzing multiple instances of CVs using Information Visualization (IV) and Visual Analytics (VA) techniques. CV3 manages a collection of résumés and suggests the best ones to include in the short list for a job application by combining well established visualization and interaction techniques with novel modeling approaches in the application domain of Human Resources (HR) and recruitment. The main contributions of our paper are:

- A unified model that incorporates all relevant data in a CV, including skills, education, work experience, awards, etc;
- The "Skill Forest" and the "Skill Tree": two novel approaches to the modeling and visualization of the candidates' knowledge and skills;
- A two-dimensional scoring system for CVs computed against specific job requirements (in terms of skills) that also portrays the overall knowledge of the candidate in the field;
- A prototype that allows users to interactively explore, compare, and analyze multiple instances of CVs in an interactive exploration environment;
- The results of the evaluation of our solution by means of a user study by professional recruiters;
- The discussion of the lessons learned and exploration of open challenges for future research.

The remainder of this paper is organized as follows: in Section 2 we discuss the related work; in Section 3 we present our methodology; we describe and validate CV3 design respectively in Sections 4 and 5; Section 6 concludes the paper.

2. Related Work

Our primary focus is dedicated to the visualization, comparison, and analysis of the hierarchical and spatio-temporal data contained in CVs in an interactive exploration environment. Such data are present in certain sections of a CV, like the candidate skills or work and education history.

In Section 2.1, we first illustrate previous work about the interactive exploration and comparison of CVs. In CVs the entries in the work and education history sections can be seen as events. Events have a temporal dimension - start and end date, a spatial dimension - a location associated with the event, and other possible metadata, such as title, description, media, etc. If the end date is not specified we can assume that it is an ongoing event.

In Section 2.2 we discuss and establish the State-of-the-Art techniques for visualizing time- and spatially-oriented data in CVs. In Section 2.3 we will discuss the established visualization approaches of hierarchical data. In CVs, candidate competencies are generally organized following a (shallow) hierarchical structure. Europass [Eur] divides them in "Digital skills", "Communication skills" etc.; Linkedin professional social network [Lin], automatically assigns a skill to a group following a built-in ontology, with each one belonging to a single category (inclusion).

2.1. Visual Comparison of CVs

Résumé analysis and comparison has been used in several application domains to evaluate career mobility and progress patterns [GR04, SCM06]. Lately, massive publicly accessible résumés have emerged on the internet. To tackle the problem of providing a quick and unmanned tool to categorize CVs, Zhang et al. presented *ResumeVIS* [ZWW17, WZXW17]. ResumeVIS is able to parse data from semi-structured résumés, focusing on career progress patterns, social relationships, and mobility (type of organizations previously served, such as government, non-profit, etc.) of the candidates. The main view allows to select a candidate, whose career trend and interpersonal relationships are represented respectively with a line chart (named "career trajectory chart") and a node-link graph visualization (star-shaped, with the candidate in the center). Statistics about all the parsed CVs are visualized using a histogram, while the mobility information is displayed using quadrant diagram. While effective for categorizing and browsing large amounts of semi-structured CVs, the system is specifically tailored for the chinese labour market and does not provide a scoring system. Moreover, the system does not support any geographical information, and the authors state this to be an open challenge worth exploring. Jafar et al. [JWB17] present an ontology-based visual analytics approach to get insights from CVs. The ontology comes from the ACM Computer Science Curricula Report [Joi13] that describes a taxonomy of terms that follow the "KA-KU-LO" model: Knowledge Area, Knowledge Unit, Learning Objective. To improve the expressive power of the existing model, it has been extended to also include "competencies": each one of them is associated with Knowledge, Skills, and Dispositions. The authors gather data from a survey by Longenecker et al. [LJFC13] and map them to the ontology. Finally, the results are visualized using heatmaps, stacked bar charts, and wordclouds, consequently moving the scope of their research to CV categorization rather than ranking/comparison. Existing commercial solutions for the assessment and comparison of candidates include *Applicant Tracking Systems* (ATS) [MBB14]. ATSs are built to better assist management of résumés, applicant information, and help companies in the task of recommending candidates that best match a given position's requirements. They are well suited for typical tasks such as talent acquisition and evaluation. These applications are based on statistical analysis of keywords, skills, former employers, and years of experience and only identify specific attributes in a CV. However, each CV needs to be manually analyzed, compared with others, and evaluated to find the best applicant. These systems do not take into account the career paths of the individuals, which are a key factor in identifying successful candidates, nor do they provide an intuitive way of comparing multiple candidates simultaneously.

2.2. Spatial and Temporal Data

The most common and intuitive visualization technique for representing time-oriented data is the use of timelines. Timelines typically display a sequence of events on a horizontal axis depicting time. This visualization method provides the user with a quick and clear overview of the temporal dimension of the data represented in the work and education sections of a CV. LifeLines by Plaisant et al. [PMR*96] is a well known approach for visualizing temporal data using timelines. Lifelines provide a general visualization environment primarily focused on multiple personal histories. A comprehensive survey and analysis of the design space of timeline visualization techniques is available from Brehmer et al. [BLB*17]. One of the main drawbacks of using timelines in non-interactive (static) environments is that only a small subset of the event's information can be displayed - we can see the start and end date, along with the title of an event but the description, location, the type of event, and other metadata are not visible. Furthermore, timelines do not account for the spatial information associated with the event. These issues limit the usage of this approach in the HR application domain.

To incorporate both the spatial and temporal aspect of events into a single visualization we can use multiple coordinated views [Rob07] or isosurface [Lor95] approaches. In spatio-temporal visualization, multiple coordinated views refer to a visualization technique that presents the temporal and spatial data in two separate views (e.g., timeline + maps). The same data is shared across both views with each presenting a different perspective enabling interactive discovery, analysis, and comparison of the data. In contrast to multiple coordinated views, isosurfaces take on a different approach, namely incorporating both the spatial and temporal aspects of the data in a single visualization. This is done in a three-dimensional space, where the horizontal axes (X and Y axis) represent the spatial data (e.g., a map of the underlying geography) and the vertical axis (Z axis) depicts the variation in time. These techniques are based on Hägerstrand's time geography [Häg89] - the study of space-time behavior of human individuals. Since CV3 follows a multiple coordinated views approach, we will focus on the techniques that are categorized as such.

The VA system 'VAiRoma' presented by Cho et al. [CDW*16] attempts to couple State-of-the-Art text analysis with an intuitive visual interface to assist users in exploring and analyzing events, trends, places, times, and the relationships between them in the context of Roman history. The VAiRoma interface is composed of three primary views - timeline view, geographic view, and topic view. The timeline view uses a stacked graph approach to visualize trends and topics over time, where each point in time represents the number of articles related to a certain topic. The geographic view utilizes three different layers to visualize the spatial data - heatmap layer, points layer, and pin layer. Furthermore, VAiRoma offers a topic view, which utilizes multiple visualization techniques for displaying topic hierarchies, content, and topic weights. Each of the views utilizes different visualization techniques that are interlinked to allow users to gain insights through analyzing and exploring large amounts of historical data from different perspectives. Although this specific system is primarily suited for analyzing and exploring historical data, we believe some components can be adapted for the comparison and visualization of multiple instances of CVs.

Jänicke et al. [JFS16] propose the development of an interactive visual profiling system for musicians, which utilizes IV and VA techniques to support users in determining similar musicians. The interface consists of various columns for visualizing the multifaceted data of a musician's CV attributes. The different columns represent metadata related to a musician's professions, where they worked, and their denominations. Consistent color-coding is used throughout the interface to provide intuitive means of visually distinguishing different musicians. The relationship graph illustrates a musician's social network, where the edge length maps the strength of the relationship. The map of the visual profiling system displays all places of activity for the selected musicians. The idea behind this visualization technique is to provide an intuitive means of displaying and interpreting the information associated with an activity region and to support users in the discovery, exploration, and comparison of different activity regions.

For sake of completeness, we suggest the paper by Aigner et al. [AMST11] for a comprehensive survey of time-oriented data visualization techniques. A systematic overview of approaches, techniques, and methods for exploring and visualizing spatial and temporal data is presented by Adrienko et al. [AA05].

2.3. Hierarchical Data

A hierarchy can be represented as a set of elements and a set of recursive inclusion relationships between them that depict the structure of the hierarchy, starting from a single element, a "root". Such structures can be easily represented as "rooted tree" graphs, mapping the elements as vertices and the inclusion relationships as edges. The importance of rooted trees in representing simple relationships is recognized [BETT98], with extensive research carried out on how to draw such graphs. A very well known approach is the "Layered tree drawing", which yields a downward planar layout. In this approach, vertices at a distance i from the root are placed on layer L_i, with the root on layer L_0. Each subtree is drawn independently in a recursive fashion and then appended to the root following a divide-and-conquer philosophy. Another approach is the radial drawing algorithm. It still follows the principle of the layered layout but in this case the root of the tree serves as the origin of concentric circles where the layers are arranged expanding outwards. For a more in-depth analysis of rooted tree layout algorithms please refer to the book by Di Battista et al. [BETT98]. Balloon trees [LY*07, HMM00] are a visualization technique for trees in which each subtree is enclosed in a circle centered in its root. The radius of such a circle depends on the number of nodes belonging to the subtree, and Lin et al. present an algorithm to obtain a balloon tree visualization with optimized angular resolution [LY*07]. Hyperbolic trees are a focus+context approach for visualizing large hierarchies [LRP95, LR96]. The hierarchy is laid out on a hyperbolic plane which is then projected to a 2D drawing. This approach proved to be effective and many related papers and applications followed [Mun98, DCL*17], making also its way to the exploration of data in immersive 3D environments [ZZLL17, KMLM16]. Other visualization approaches that leverage 3D graphics include Cone Trees [RMC91] and "botanical" visualizations such as the one by Kleiberg et al. [KvDWVW01].

An alternative to node-link visualizations are space-filling techniques. The hierarchical information is encoded by containment rather than with straight lines. Containment shows the complete information about the hierarchical structure, whereas edges only show pairwise relationships [Mun14]. Treemap layouts are a prime example of this technique [Shn92]. In this approach, the elements of the hierarchy are represented as squares or rectangles, with its descendants enclosed in the area allocated to their ancestors. By relaxing the constraint of only having rectangular shapes, we obtain Voronoi diagrams [BDL05]. This class of treemap layouts is based on arbitrary polygons and present an improved aspect ratio and present advantages in the identification of boundaries between and within the hierarchy levels. Alternatively, circular shapes can be used [Wet], however, while aesthetically appealing, they suffer from reduced space efficiency.

3. Problem Domain Characterization and Abstraction

We employ the nested model approach by Munzner [Mun09] as our main design and validation methodology. At the first level we characterize the problem domain by utilizing the design triangle framework proposed by Miksch et al. [MA14]. The first step towards designing and developing a solution is to answer the following questions:

- What kind of data are the users working with?
- Who are the users?
- What are the tasks of the users?

To validate our approach against domain threats [Mun09] and fully understand the problem domain, we conducted a preliminary user-centered design study in the format of semi-structured interviews [Woo97] . The interviews lasted between 20 and 30 minutes and the main objective was to get acquainted with the participants' individual responsibilities, workflow, and the hiring process as a whole. In our user study we had six participants employed in HR departments of various companies. The participants had different positions and responsibilities in the department, including two interns in smaller companies, one hiring manager in a larger company, and three recruiters with experience in talent acquisition. By listening to their experience, we were able to derive and formalize the data model and the tasks that representatives of the HR department face in the process of compiling the short list of candidates for an open job position. In the following sections we focus on each one of those aspects, describing the insights that steered the development of CV3. In Section 3.1 we formally describe the data model of a CV; in Section 3.2 we discuss the users that were considered when designing the system; in Section 3.3 we illustrate the tasks.

3.1. Data

CVs are semi-structured documents and are an encapsulation of a candidate's personal information, background, and skills. To identify the data types and model, we have analyzed several résumés, collected from various sources, and abstracted the information into a generalized model for CVs which we outline in the following:

- **Contact Information**: name; address; e-mail; telephone.
- **Skill set self-evaluation**: recursive hierarchy of topics; knowledge level (Basic to Expert).
- **Employment history**: traineeships; work history; academic positions.
- **Education and training**: high school; university; graduate school; post-doctoral training; publications.
- **Professional qualifications**: certifications; awards; languages.
- **Personal Information**: birthplace and date, gender, personal summary, profile picture (for the purpose of the system all this information is optional).
- **Other information**: interests; hobbies; references.

Nowadays, it is common for large companies to ask candidates to fill out a form during the job application with the data organized similarly as above, in addition to uploading their CVs, for quick categorization. From the structure of a typical CV we can identify several sections, each having a different type of data associated with it. There are four major data types that can be distinguished from this model:

- **Nominal data**: general, personal, and contact information, etc.
- **Hierarchical data**: professional skills and competencies.
- **Ordinal data**: social skills and languages.
- **Spatio-temporal data**: professional and academic history

3.2. Users

The HR department of an organization oversees numerous aspects of employment, including recruitment, talent acquisition, and performance management. From our interviews, we could classify the users into two distinct user groups: non-expert "novice" users (interns and hiring managers), and experts (the recruiters). Novice users have experience in the general process of hiring and interviewing candidates, are acquainted with the responsibilities of employees in an HR department, and know the characteristics of good and bad CVs. The expert users share the same knowledge as non-experts and have experience in talent acquisition and CV comparison possibly using an ATS. Additionally, they possess domain knowledge and can offer us insights regarding the limitations of such systems. In our approach we aim at providing a tool that can accommodate the needs of both user groups, as opposed to ATSs, which in our experience are only known to an expert audience.

3.3. Tasks

The purpose of this section is to outline the users' needs and provide support for the successful execution of their tasks. To understand the problem domain, the hiring process, current challenges, and identify potential bottlenecks and unsupported tasks in the tools that are in use, we asked the participants of our preliminary design study a series of questions on the following topics:

- Responsibilities as a hiring manager and the recruitment process.
- Characteristics of good and bad CVs.
- Relevant data to quickly assess the quality of CVs.
- Comparison and assessment of CVs.
- Time spent on searching, comparing, and assessing candidates.
- Tools used in the HR department and features that are potentially missing.

As a result from the interviews we had a clearer overview of the hiring and talent acquisition process, gained deeper insights regarding the data and tasks and received a better understanding of what tools and systems are in use. The tasks along with a short description are provided in the following list:

- **T1: Explore** - The proposed solution should provide a straightforward and effective interface to access the applicant information. The importance of this feature is twofold: in first place, it should allow users to view a specific candidate and explore the sections of her/his CV in more detail; moreover, it should allow the user to have an overall view of the entire CV database.
- **T2: Assess and Evaluate** - The solution should provide effective visualizations for the CV data, with the goal of assessing their quality at-a-glance, also highlighting patterns that would be difficult to see on paper. The system should visually convey to the recruiter information about a candidate's skill set, in order to evaluate the candidate's overall and specialized knowledge about a particular domain of expertise. Additionally, the system should provide an effective way to visualize the time-oriented and geospatial data, encapsulated as events, in CVs. This includes gaps between employments (in terms of time elapsed), concurrent jobs, correspondence between skills and employment history, and mobility (in terms of experience abroad). Those are considered relevant factors in assessing the résumés and determining which candidates are to be included in the short list.
- **T3: Compare** - Our approach should provide the recruiter with a scoring system, capable of suggesting a subset of candidates which are the most knowledgeable against a specific set of skills required by a job application. Furthermore, recruiters also need to consider the general experience of the candidate in the specified field, with this being one of the most difficult tasks to carry out with manual comparison of paper CVs. For this reason, the system should model the skills accordingly, and include a ranking function that takes this specific need into account. Once a short list of candidates has been compiled, the solution should allow an in-depth comparison between several candidates, using effective visualizations of common skills, work experience, education, and job mobility. The visualizations should further assist the recruiters in determining patterns, commonalities, and outliers in terms of career development.

4. CV3's Design

In the following Section we describe the design of CV3 and discuss how the system supports the tasks presented in Section 3.3. In Section 4.1, we describe how we modeled the candidates skills; we present the scoring system in Section 4.2; we conclude with Section 4.3 where we discuss the design of the views included in the system. CV3 is an open-source web application: the code and a live demo can be found at `https://github.com/velitchko/cvthree`.

4.1. Skill Forest

Our observations (see Section 3.1) suggest that the skills can be represented as a hierarchy. We propose a modeling approach in which each individual skill is modelled after a rooted tree. It depicts the hierarchy of a specific skill (i.e., "JavaScript") or a category (i.e., "Programming"), which represent nodes in the tree. A skill node comes with a name and a corresponding expertise level (which can either be "Basic", "Novice", "Intermediate", "Advanced", or "Expert" [Nat]); a category node cannot be a leaf and is not associated with a skill level. Therefore, the knowledge of the candidate is represented as a "Skill Forest". When we visualize it, a common faux root node is created and connected to the roots of all the individual trees, thus creating a "Skill Tree" (see Fig. 1(B)). Skill trees have been used extensively in video games (the "Diablo" series made it famous back in 1996) as a visual way to track the player progression in the character's abilities: research on knowledge representation investigated their use to allow students of "Massive Open Online Courses" (MOOCs) to easily keep track of the new skill acquired with each new lecture [AKSS17]. With this grounding and our observations we decided to explore the use of skill trees to represent the knowledge of each individual candidate (**T2**): they are familiar, flexible, and can be easily adapted to support new tasks. The parent-child and sibling relationships in a tree can be used to understand which skills are respectively specializations and branches of others: we exploited this information to conceive a score that goes both vertical (Specialization) and horizontal (Diversification) in the tree. To the best of our knowledge, this is the first time that this modeling approach has been used in the domain of HR and recruitment.

4.2. "Specialization" and "Diversification" Scores

In order to suggest the best candidates given a specific set of skills (**T3**), we designed a two-dimensional scoring function that we use to competitively rank the candidates. This information is then used to create appropriate and meaningful visualizations supporting the user on the assess and compare tasks (**T2** and **T3**). The input of the function includes the "query", an array of skills with corresponding knowledge requirements (among the 5 possibilities shown in Section 4.1) and the candidate's Skill Tree. The knowledge requirements defined in the query are mapped to numerical values in the range $[0.2, 1]$ and act as skill weighting factors. In turn, the knowledge "levels" defined in the candidate's Skill Tree are mapped in the range $[1, 5]$. The first dimension of our ranking function is called "Specialization" score and its values can lie in the range $[0, 10]$. It is more focused on precision and provides a relevance measure of a candidate's CV according to specific job requirements defined in the query. For each candidate, the Specialization score is computed using the following procedure:

1. For each skill in the query, find matches in the Skill Tree;
2. For every matching skill, increment the score by multiplying the skill weighting factor and the candidates knowledge level;
3. As a final step, average the obtained score by the sum of the skill weighting factors (for both matching and not matching skills) and scale it so that it falls into the range $[0, 10]$.

The second ranking function is called "Diversification" score. It expresses the candidate's knowledge about skills related to the ones in the query. It is intended as a way to contextualize the Specialization score by giving a measure of how much a candidate knows over a specific field, rather than about specific skills. The score is computed using the following procedure: once a matching skill has been found (as in the Specialization score), if its node has children, the score is incremented by the amount of children; otherwise by the amount of siblings. The final output of our scoring system is a pair of coordinates, that can be plotted on a scatter-plot (see Fig. 2), easily providing a visual way to compare the candidates. We exclude candidates scoring $(0, 0)$ from the results. While the rationale behind the Specialization score is straightforward, the Diversification score design is inspired by the Skill Tree structure itself. On the one hand, if a matched node has children, it means that the candidate also has a more specialized knowledge than requested. On the other hand, the presence of siblings of the matched skill, reveals a broader scope of knowledge in the field of interest. We count the number of children/siblings regardless of their knowledge level: the Diversification score has the purpose of contextualizing the knowledge of the candidate immediately "around" specific required skills, with an orthogonal semantic than the one behind the Specialization score. If both the cases occur (the matched node has children and siblings), we give precedence to the descendance relationship, this choice was made considering the feedback obtained in the preliminary interview. We wanted the Specialization and Diversification score to complement each other and provide a well-structured overview of the candidates' skills in the scope of fulfilling **T3**.

4.3. Views design

CV3 is composed of four views: (1) the List View, (2) the Compare View, (3) the Profile View, and (4) the Add/Edit View. In the following Section we describe the first two in detail and give a short description of the others, along with an explanation about our design choices,

List View

The List View supports the recruiter in: (i) consulting the CV database (**T1**), (ii) accessing single profiles (**T1** and **T2**), (iii) querying the database for eligible candidates given a set of skills, and (iv) selecting a set of candidates for in-depth comparison (**T3**). At the top of the view, we placed a form for filtering the candidates and querying the database. The form has two functions: (i) it is intended to filter the candidates according to occupation, location, and language(s); (ii) it allows to define a set of skills, with the corresponding requested knowledge level, which will be used to rank

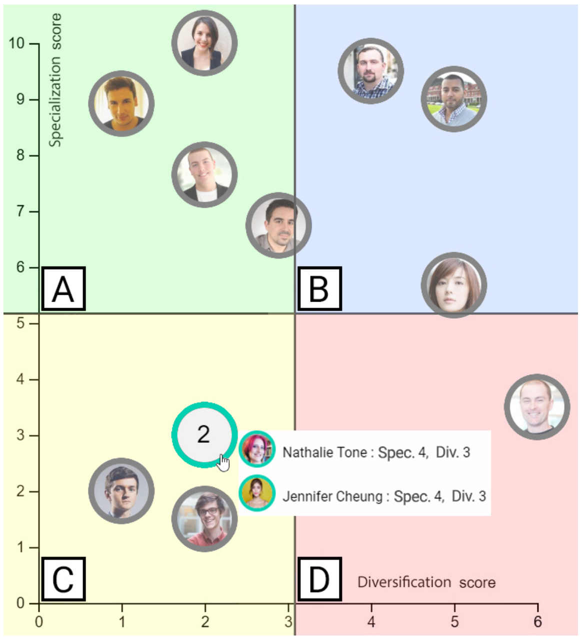

Figure 2: *Scatterplot showing the score of the candidates. The different sectors convey a different level of knowledge.*

the candidates according to the scoring function. Only the CVs that fulfill the filtering conditions (in an OR fashion) will be ranked. Proceeding downwards, we show the candidates "cards" (see Fig. 1 (A)) with the portrait of the candidate, name, age, full details of current job (position, company, city and state), icons for spoken languages, the average job duration, years of experience, and the number of unique locations where s/he had work experiences. The "deck" can be sorted in several ways, including age, years of experience, and many more, using a select box at the top left corner of the cards area. By combining the design of the cards and the sorting tools, we present the recruiter a concise but comprehensive visualization of the whole database. The choice of the information to show on the cards was made by picking up the data that the recruiters search first in a CV according to our interviews. A click on any card accesses the Profile View (see paragraph below) of the corresponding candidate.

Once one or more skills are selected, the search can be performed. The results are displayed in a scatterplot (see Fig. 2). On the x-axis we plot the Diversification score, while on the y-axis we show the Specialization score. The points in the scatterplot display the candidates' profile picture (if present). In case of overlapping coordinates, we show a single point, depicting the number of overlapping elements; on mouseover, a tooltip appears, displaying details about which candidates share the same score. We are aware that the scatterplot can become very dense with many applicants: the grouping of overlapping candidates attempts to improve both the scalability and clarity of the visualization. We chose a scatterplot to display our ranking due to its efficacy in providing an overview and finding extreme values and outliers [Mun14]. In this case, we overview the approximate knowledge of several individual CVs at the same time, significantly accelerating the task of build-

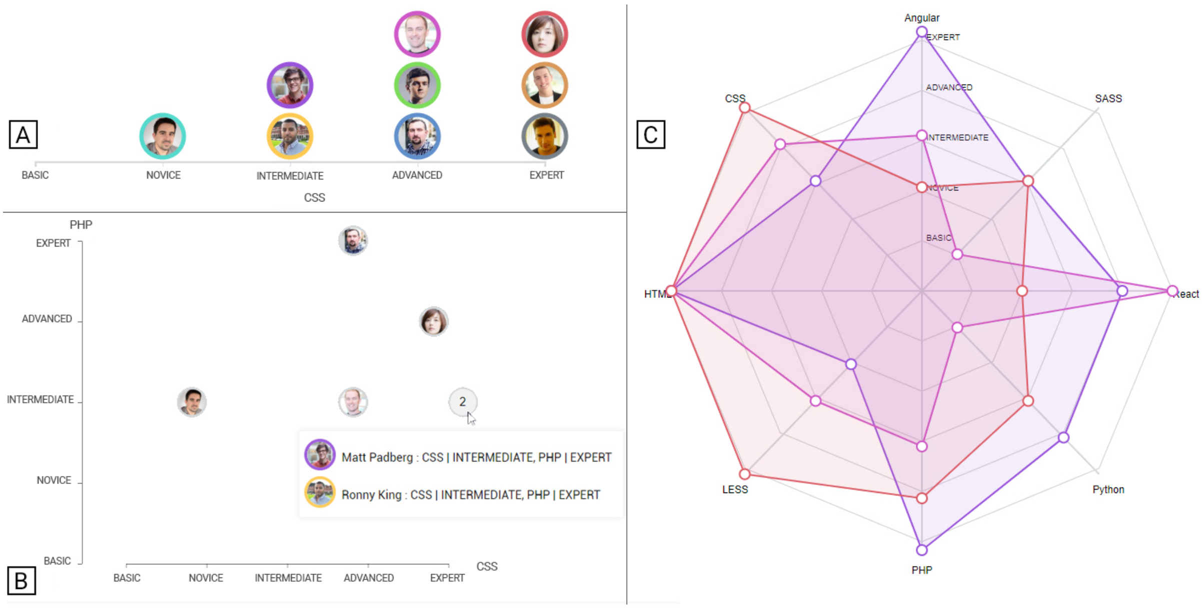

Figure 3: *Common skills visualization. According to the number of common scores we use different techniques. For a single skill we use a bar chart with the candidates portraits stacked depending on their knowledge (A). For two common skills we display the candidates expertise in a scatterplot where we plot the common skills on the x- and y-axis (B). For three or more matched skills we construct a radar-chart where each axis is a unique common skill (C).*

ing a short list for evaluation. The area of the scatterplot splits into four quadrants (see Fig 2): in the first quadrant (top-left A) we find people with a high Specialization score, but with a lower Diversification score. In the second quadrant (top-right B) we find the candidates who are both proficient in the requested skills and possess high overall knowledge in the field, thus being the most interesting for a specific application and likely to be included in the short list. In the third quadrant (bottom-left C) there are people with low Specialization and Diversification scores. Finally, in the fourth quadrant (bottom-right D) we find people with moderate expertise in the requested skills but with significant overall knowledge. Interaction is made by brushing: the recruiter draws a rectangular shape on the scatterplot area and the points falling into the rectangle will be added for comparison; the rectangle can be moved around the area and re-sized. It is also possible to add/remove résumés to/from the comparison by clicking the appropriate button on the cards or by selecting the points in the scatterplot. By clicking on the "Compare" button the view is switched accordingly.

Compare View

The Compare View is used to compare the candidates who made it to the short list. To avoid excessive clutter, we have set an upper bound of 15 candidates that can be concurrently compared. This design choice sets a limit to the size of the short list: we overcome this constraint with interactivity, by allowing the recruiter to easily add or remove candidates from the view (as we will describe in this paragraph). The goal is to provide a comparison of the salient sections of the candidates' careers, experience, and skills (**T3**). Here we opted for a multiple coordinated views approach. In Fig. 1(A), we arranged the cards of the selected candidates to provide quick side-to-side comparison. On top of each card there are three switches (left to right): the first permanently highlights the candidate's features across all views; the middle one hides the candidate, and the last one removes the candidate from the comparison altogether. Below the cards, we placed the "Skills" section. Here we directly compare both the skills the candidates have in common (see Fig. 3) and the combined Skill Tree of all the candidates (see Fig. 1(B)). This specific design choice was made to fulfill both **T2** and **T3**, and follows a focus+context approach. The "focus" is on the common skills: it makes more sense to directly compare the knowledge level on those only, considering it is more than likely that the ones required by the job application will appear here. To do so, different visualizations are suggested depending on the dimensionality of the data, which depends on how many skills the selected candidates have in common. If only one is matched, we show a bar chart, with the skill level plotted on the x-axis and the portraits of the candidates stacked on top the corresponding level (see Fig. 3(A); if two are matched, we visualize a scatterplot, with a skill on each of the two axes (see Fig. 3(B)). Finally, if three or more skills are matched, a radar-chart (also known as spider-chart) is shown, with each skill plotted on a different axis, which creates a polygon for each candidate filled with her/his color (see Fig. 3 (C)). The radar-chart is an appropriate choice because it allows for easy recognition of outliers and commonalities [CCKT83].

The context information is given by merging together the Skill Forest of each candidate into a single result tree (see Fig. 1(B)). At first, the result tree contains a faux root node. We then append every tree of each forest to this node. We do not allow duplicates in the result tree, therefore, in case of shared skills, we retain the information about the candidates possessing them along with the cor-

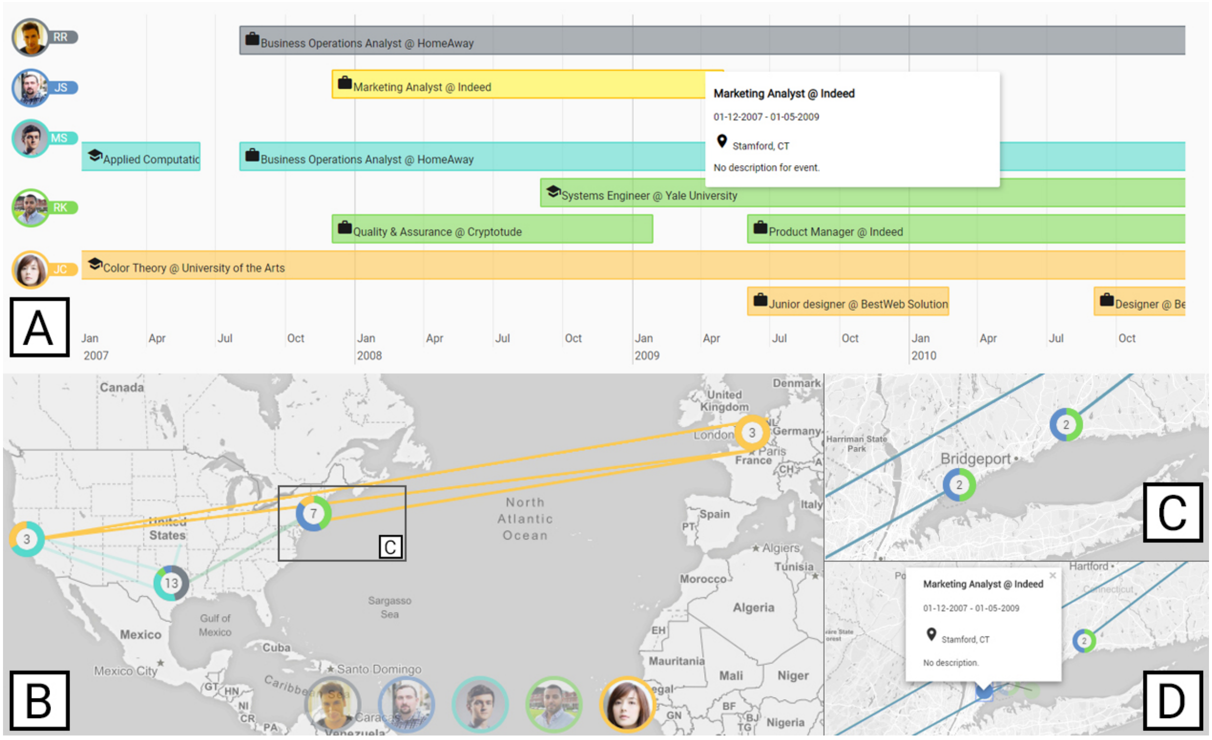

Figure 4: *Timeline (A) and Map (B-D), the linked views of the candidates' events. In case of overlapping markers these are clustered together (C). Each event in the timeline is associated with a tooltip where we display detailed information related to the event (D).*

responding knowledge level. The matching is performed by case-insensitive string comparison of the skills' names. By construction, the result tree is a representation of the combined knowledge. On each node, the outer ring is split uniformly into sections depending on the amount of people that share the given skill and each section is colored according to the candidates who own that skill. Hovering with the mouse on each node shows a tooltip with the names of candidates and their corresponding expertise. In this case, we also encode the expertise as the opacity of the border (higher opaqueness corresponds to a higher expertise) but also show this information in a tooltip on demand. We choose a radial tree layout over a layered one because of its better aspect ratio and area efficiency as the number of nodes to display grows, aiming at achieving better scalability. We also considered using a treemap, but intermediate nodes are relevant for both interaction and visualization, so a node-link visualization is better suited for our goal. Furthermore, pathfinding tasks such as highlighting the Skill Tree of an individual candidate are not supported in a treemap visualization [GFC04].

Below the skills area, we put the "Timeline" (see Fig 4(A)) and "Map" (see Fig. 4(B-D)). With these last two visualizations, we aim at completely fulfilling **T2** and **T3**. The timeline shows the aggregated temporal data about the candidates' career developments. As already mentioned in Section 2, events have a temporal and spatial dimension along with possible other metadata. Furthermore, they can be associated with a category (i.e. education, work, awards etc.), which is depicted by a specific icon. The timeline is searchable by location or by category: in this way, it is possible to compare the different careers from several points of view, looking at gaps in employment, concurrent jobs, and job variety. It is possible to have extra information about each event by hovering over it. A legend shows which category each event belongs to. The temporal data about the candidates' career development is additionally reflected in a spatial context as to support recruiters in also assessing their mobility in the map below. Here we plot the geographical data associated with each event in the CVs. We allow the recruiter to evaluate the mobility of the candidate and compare it with the others. The events are represented as points on the world map, colored as the candidate and connected by a line. By clicking on them, a tooltip shows a summary and the timeline re-orients itself to focus and highlight the corresponding event. If, considering the zoom level, two or more points are geographically close, they are grouped together in a single marker that bears a number representing the amount of events. The outer ring is split proportionally to the number of events belonging to each candidate. By clicking on such marker(s), it "blooms" and shows the single points, which are now interactive.

Profile View and Add View

With the Profile View and Add/Edit View we fulfill **T1** and **T2**. In the Profile View, we show all available information about the candidate, including the proficiency in the spoken languages according to the "Common European Framework of Reference for Languages" [Cou], the candidate's Skill Forest, and timeline. In the

Add/Edit View, candidates can add or edit their information using a form.

5. Validation

In this Section we describe how we validated the proposed system. In Section 5.1 we describe the procedure we followed, in Section 5.2 we discuss the results of our interviews, and in Section 5.3 we summarize our findings and highlight the lessons learned.

5.1. Domain Expert Validation Procedure

We conducted the evaluation of CV3 by means of a small scale user study with domain experts. We conducted our study as a task-based evaluation: we asked the participants to think aloud while using CV3 to perform tasks, so that we could gain insights into how they interacted with the system. Our hypotheses are as follows:

- **H1:** CV3 does not need extra training for recruiters and managers, since it fits the current process of selecting candidates without introducing new steps or changing the work methodology;
- **H2:** CV3's scoring system (Specialization + Diversification) and result visualization assist the recruiters in assessing multiple candidates' capabilities on a specific query;
- **H3:** CV3 skills modeling and visualization approach is a suitable representation of the candidates' knowledge.

We conducted the user study with four participants: two of them are managers of medium-large enterprises and are responsible for interviewing and selecting candidates for hiring. One is responsible for the recruitment in a medium-sized company and the last one has experience evaluating CVs in an academic environment. We chose the experts as to test how CV3 would perform in various environments with different foci and users with diverse expertise. Each interview lasted between 60 and 90 minutes. The sessions were structured as follows: (i) introduction to the system, (ii) hands-on testing, (iii) task-based evaluation, (iv) general feedback and opinions. Since there were no publicly available datasets that fit our data model, we merged information from real CVs and online identity generators to create 15 different realistic résumés. We tailored the résumés for software/web development careers, with varying age, skills, education, and work experience. The tasks focused on providing answers to our hypotheses. We chose the tasks to determine the efficacy of each visualization on its specific focus and how they worked together:

- **VT1:** Select the candidates with the highest knowledge for a given query (this selected pool will be used for the other tasks);
- **VT2:** Assess the geographical data of the selected CVs in terms of proximity (to the recruiter) and job mobility (in terms of geographical movement);
- **VT3:** Compare the education, work experience, and other events of a candidate to all the others in order to find outliers and assess their potential;
- **VT4:** Evaluate the expertise of the candidates based on their common skills and overall knowledge.

With the tasks completed, we asked the experts for their feedback about the overall experience; we asked for their opinion about the ranking system, and, more generally, insights into how they would use CV3 in a real scenario.

5.2. Discussion

In this Section, we will discuss how each participant solved the given set of tasks and whether we can confirm or deny the associated hypotheses. We start with **VT1**. All experts quickly completed the task by using the skill search form in the List View and the resulting scatterplot (see Section 4.3). The experts agreed that the two-dimensional score visualization was insightful and gave a quick but reliable impression of the candidates' skill background. With different wording according to their own experience, all the experts agreed on the usefulness of the Diversification score, stating that it would most likely allow people usually overlooked to have better chances to be part of the short list. However, they pointed out the lack of transparency on how the query is constructed: the skills are queried in an "OR" fashion, and while the experts mostly agreed that this is a reasonable approach, they suggested that providing the option to customize the query construction could cover more possible usage scenarios. All experts suggested to implement a more guided input on the query form, such as auto-complete on each field.

With **VT2** we want to understand how the geographical data is conveyed to the users. The experts agreed in mobility being useful in providing contextual information about the candidates' careers, with some of them pointing it as being "relevant" in the selection process. According to the different experiences of the experts, mobility and proximity had varying impacts in the selection process: people who moved more might be more willing to relocate opposed to those who did not. All the experts completed the task using the information on the cards, the timeline, and the map. The map was praised for its clarity and all the experts could easily identify the mobility patterns of the candidates. However, they pointed out the lack of temporal information on the map, which made the task of finding the closest candidate(s) harder. The linking with the timeline partially helped in coupling the temporal with the geographical data.

VT3 task is conceived to assess the usefulness of the timeline in visualizing the career experience of the candidates. We asked the experts to assess and compare the careers of the candidates over time. They used the information on the cards to have a quick reference of the people with most working years and job duration. The experts then verified and better contextualized this information using the timeline. A couple of them found the timeline confusing at the beginning (especially with many events) but it was mostly helpful when completing the corresponding tasks. Filtering played a major role, especially in the assessment and comparison of the education. Furthermore, the experts could quickly find the gaps between different and concurring events, which is information they considered relevant. The interactions were useful with some minor complaints about the timeline interacting with the mouse wheel. One of the experts pointed out that one of the most interesting aspects of the timeline was the automatic calculations of the years of experience: in this way, rounding and bias (human error) are avoided. Finally, the concurrent (but filterable) display of all the different categories was praised: however, all the experts reported a difficulty in interpreting the icons due to the lack of a legend (that was later included).

VT4 focuses on determining the skill set visualization of the selected candidates. Our intention is twofold: we want to evaluate how the experts use the common skills chart and the Skill Tree to perform tasks that involve the candidates' knowledge.

Among the other views in the system, this is the one that required the most clarification to be completely understood. The experts found it too colorful and confusing at the beginning. However, after the design rationale was explained, all the tasks referring to this view were solved by the experts with minimum to no assistance. In particular, the experts praised the interactions between the two views, with highlighting playing a major role in keeping track of the candidate's profile also in larger skill trees. Highlighting was also useful in path-finding tasks, i.e. finding a specific candidates' set of skills (subtree). The coloring of the tree nodes was very efficient in depicting the most (and least) common knowledge between the selected candidates. In the Compare View, experts used the tree to find the subset of candidates that shared the most skills and then used the corresponding radar-chart for direct comparison. Experts did not understand why the common skills visualization changed according to the number of common skills, asking for a more detailed explanation about why the radar-chart was swapped with other completely different visualizations.

General feedback was mostly positive, with all the experts praising the idea of the Diversification score: one of them explicitly stated that in a software development company, given the high amount of different technologies/skills needed for every project, it is hard to find a profile that fits perfectly. For this reason, a more inclusive ranking would be useful in this application domain. The scatterplot for candidate selection in the List View was appreciated as an easy, visual, and interactive solution to quickly categorize the CVs. However, what really caught the attention of the experts was the Skill Tree: they praised both the Skill Forest idea and how it was implemented in the Compare View, effectively conveying the overview of the skills of all the selected candidates at the same time. Moreover, we noticed that the experts were generally faster in completing the tasks involving the use of the Skill Tree. Even if one expert found it confusing at the beginning, afterwards they agreed about its usefulness in a real-life situation. The common skill visualization needed the most explanation, compared to the other views. Constructive criticism included improvable user experience on the timeline and on the map, and, in general the experts preferred to have a more informative interface, especially when making queries.

5.3. Lessons Learned and System Limitations

According to our experience and the results of the expert interviews, the findings seem to confirm our hypotheses. Based on the general feedback and the results of expert interactions on **VT2** and **VT3**, it appears that CV3 would fit in the existing workflow of a HR department, thus confirming **H1**. Feedback on **VT1** seems to support **H2**: the proposed scoring and visualization fulfilled its purpose in providing an overview of each candidate's competence on a specific set of skills. Moreover, the experts praised our two-dimensional scoring and the idea of evaluating the overall knowledge in a succinct way (Diversification score). They explicitly stated that they were likely to include more people in the short list based on the Diversification score provided. Finally, the experts agreed on the choice of modeling the skills of an individual after a tree, and used it proficiently on **VT4**, to compare and evaluate the knowledge of several CVs. This suggests that the experts found our knowledge representation straightforward and stated that it could support their assessment process (**H3**). Overall, based on our findings in the evaluation, CV3 can indeed support the exploration and comparison of multiple instances of CVs and can assist users, that work in a HR department, with their tasks in a meaningful way. Concerning CV3 limitations, we currently match the skills of the candidates to a query using a string-based approach, thus being prone to false-negatives (such as "Development" and "Programming"). However, this tends to happen much less with skills about specific technologies (e.g., CSS, JS, etc.). An additional limitation of the system is that it does not account for missing data. The system does not penalize candidates with missing data by design, however, it also assumes that the information being processed is complete and valid, thus candidates with incomplete information could be excluded from the results. Currently, as already stated, the skills in a query are searched for in an "OR" fashion, this means that it is possible to get candidates that partially match the requirements. Some experts found this confusing, but they also found it as a reasonable approach, preferring less selective querying. Therefore, the system should also allow the user to select different options for the query construction (including "AND"-ing the constraints). On a closing note, CV3 presents known scalability limitations: we integrated some remediation measures for the List View, but we still decided to limit the maximum amount of people to include in the Compare View. Finally, the experts suggested to include the possibility of automatic résumé parsing to ease the process of entering data into the system.

6. Conclusions and Future Work

In this paper we presented CV3, a VA approach for résumé comparison and visualization. CV3 offers multiple visualizations for the data represented in CVs, provides a scoring system to suggest the best candidates for a specific application, and allows for interactive exploration, assessment, and comparison of multiple CVs. We have evaluated our solution by conducting a small scale expert study and have presented it to colleagues and visualization experts as well for valuable feedback and future work directions. To the best of our knowledge, CV3 applies modeling, interaction, and visualization techniques unprecedented in this application domain. We believe this approach is a step forward towards applying IV and VA techniques in the area of recruitment and HR. Other than tackling the current CV3 limitations, interesting future work includes investigating ontology-based Skill Tree matching/comparison techniques. Moving from a simple string matching to a more *fuzzy* approach would possibly provide more meaningful and accurate results. Additionally, this extension would allow the system to also recommend candidates based on more flexible similarity metrics. Another interesting improvement would be the introduction of an age-aligned timeline: events would be arranged according to the candidate's age as to compare each person's achievements at specific stages of their life.

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