Mining for Computing Jobs

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A Web content mining approach identified 20 job categories and the associated skills needs prevalent in the computing professions.

Using a Web content data mining application, we extracted almost a quarter million unique IT job descriptions from various job search engines and distilled each to its required skill sets. We statistically examined these, revealing 20 clusters of similar skill sets that map to specific job definitions. The results allow software engineering professionals to tune their skills portfolio to match those in demand from real computing jobs across the US (see the sidebar "Computing Jobs in the US") to attain more lucrative salaries and more mobility in a chaotic environment.[1]

Software engineering professionals can use these job types to appraise their own skills portfolio and better understand the skills similar jobs demand in other organizations.

Data Collection and Analysis

The first task was to find job advertisements and extract the job skills from the text. This component of Web content mining employed information extraction from semistructured documents.[2] We developed software that systematically searched Monster.com, HotJobs.com, and SimplyHired.com daily between July 2007 and April 2008 for jobs requiring a degree in computer science, management information systems, computer information systems, and other computing programs. We extracted 244,460 unique job advertisements.

The software then parsed the ad texts to identify and extract job skill terms, basing the initial set of terms on prior research.[3,4] These skills included various technical, programming, business, and soft skills. We excluded single words used in common language (such as basic) from the search so that the frequency of similar skills wouldn't be exaggerated (although we included the complete skill name Visual Basic). The final collection of skills included 239 terms and synonyms.

After eliminating ads mentioning too few skills (the organization was looking for one or two specific skills) or too many skills (the organization was most likely a headhunter looking for anyone), 209,655 ads remained. Additionally, we eliminated skills that appeared in fewer than two percent of the remaining jobs, leaving 69 skills for this analysis. Table 1 lists the skills occurring in 10 percent or more of the job ads and the frequencies in which they appeared. This article's companion Web site, the Degree-Oriented Guide to Skills in Information Technology (www.dogs-it.org/data), contains a complete list of all the skills, their frequencies, and other data.

We analyzed the data using cluster analysis, a statistical technique for classifying cases in groups that maximizes differences between groups and minimizes those within a group.[5] This technique allows classification using quantitatively derived measures while still allowing for some control in guiding clusters. This lets researchers ensure that

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Computing Jobs in the US

Although the demand for computing professionals in the US has recovered to pre-"dotbomb" levels,[1–5] the current economic downturn and threat of recession mean that professionals must focus their recruiting and job searches more sharply. Search tools connect available jobs to talent, ranging from professional "headhunters" to Web sites such as Monster.com, HotJobs.com, and SimplyHired.com. However, even a brief examination of these tools shows that US job titles vary substantially and that job definitions are often misleading. There's also an underlying discrepancy between the required skills and those that job hunters can infer from different employers' titles for similar positions. Many human relations departments develop advertisements for computing professionals starting with a fixed job title and then have the IT department add the list of skills that position requires. In our examination of job listings, we've found considerable mismatch and inconsistencies among the resulting skills and titles.

Consistent job titles and definitions composed of consistent skill sets can help software engineering personnel, educational institutions, students, and individual career planning. One of the more comprehensive attempts to provide such skill-set-based job definitions is the US Department of Labor's Occupational Information Network (O*NET) project (http://online.onetcenter.org). However, the report seems to lack systematic methods for determining which skill sets are required for which job definition. For example, for the position of database administrator, O*NET lists "knowledge of circuit boards" but not the dominant database products.[2]

Starting in the late '80s, various researchers began studying advertisements to determine what skills most IT jobs demand.[6] In the early '90s, researchers such as Chuck Litecky and Kirk Arnett expanded previous work to include systematic nationwide sampling of US newspaper ads.[7] In the late '90s and early 2000s, various studies began mapping the migration of IT job skills ads to the Internet, generally showing that most ads were migrating and that demanded skills were changing with the adoption of new technologies. Other researchers' methods included interviews and surveys, with many focusing on the importance of managerial and technical skills in computing jobs.[8–10] Occupation analysts initially created the O*NET database and supplemented it with annual surveys. However, it's often unrepresentative of actual jobs and the complete skill sets that employers might require. Additionally, research methods often don't attempt to determine which combinations of skills businesses frequently desire.

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resulting clusters are meaningful and not the result of arbitrary statistical incidence alone. Researchers can use Web content data mining utilizing cluster analysis to classify data or discover new resources.[6,7] Consequently, each cluster we derived contained ads closely related to other ads in the cluster on the basis of the skills they specified, while minimizing the relationship to ads in other clusters.

Cluster analysis revealed 20 job definitions, which we then verified using a manual review of 100 random job ads, with an overall successful classification rate of 91 percent (see the sidebar "Cluster Analysis" for a description of the process we used). Table 2 describes each cluster; Figure 1 shows the relative numbers of jobs from all job ads analyzed that were placed into each cluster.

Job Definitions

Table 2 shows the major details for each of the 20 job types we identified. Job types that have skills with lower frequencies require a more diverse range of skills. For example, a Microsoft Web developer job might require C# or ASP, but not both, resulting in lower overall frequencies for both skills. Nevertheless, it still indicates a strong preference for Microsoft-oriented technologies.

The clusters show that database skills are utilized in several different types of jobs. A database administrator is typically responsible for efficient hardware maintenance, logical database implementation, and security. Database developers can focus on database design or focus only on query writing, whereas database application programmers are

Table 1

The most frequently mentioned skills in computing job ads

Skill	Frequency (%)
Security	33.29
C/C++	28.69
SQL	27.57
Programming	26.08
Microsoft operating systems	23.18
Java/Java 2 Enterprise Edition/Java to Python	21.09
Leadership	20.10
Project management/planning/budgeting/scheduling	18.86
Software development	18.01
Oracle databases	17.19
Unix	17.15
Business strategy	17.06
Certification	14.88
Finance	13.98
XML	13.56
Generic databases	13.43
HTML/XHTML/DHTML	12.80
Open source operating systems	12.50
Marketing	12.47
JavaScript	12.10
Accounting	11.70
Microsoft databases	11.37
Object-oriented programming	11.16
.NET	10.55

expected to work on larger-scale applications supported by extensive database engines. The context of database skills significantly affects the nature of the job; thus, many different job types emphasize database skills. The job type titles reflect the specific emphasis on the database skills required.

Similarities among the skills required in each of the clusters suggest that we can abstract the 20 job definitions into five larger general job classifications: Web developers, software developers, database developers, managers, and analysts, shown in Figure 2.

For the Web developers group, job types focus on different Web technologies and emphasize required skills differently. For example, the Java database Web developer jobs requires Java and Java server skills along with Java and database programming skills. The Microsoft Web application project analyst job requires skills for technologies such as active server pages and C#.

The software developers group consists of five clusters of traditional non-Web-based development, with moderate demands for programming in general, software development, and object-oriented programming skills, plus specific language skills such as C/C++, Java, or C#. For example, two clusters focus on C/C++ and generic programming skills. The two clusters are distinguished through the supplementary skills required for those jobs. C/C++ programmer jobs focus primarily on programming-language skills, whereas the system-level C/C++ programmer jobs also require skills in general programming, software development, operating systems, security, and Perl. This indicates that the latter cluster undertakes work at the operating systems level as well as supporting traditional Perl-based work.

The database developers group consists of four clusters that demand a moderately high degree of skills in SQL and Oracle or other databases along with moderate degrees of programming skills. For example, the more generic database developer jobs focus primarily on SQL programming. Other database developer jobs have supplementary focuses on Java or Microsoft skills.

The managers group consists of both personnel and technology managers. The first cluster, IT manager jobs, requires leadership, business strategy, and business skills such as marketing, finance, accounting, and business process design. This is a large group that includes diverse staff with some management. However, on the basis of the included skills, the IT managers cluster doesn't specify a purely personnel management role, which would render it quite different from the other clusters in the managers category. IT managers manage various types of systems as well as personnel and have a range of technical skill requirements. At the same time, they aren't exactly like network or system administrators, who have a much more focused role in specifically managing networks or operating systems. So, these clusters are somewhat similar and belong under the same parent category. Conventional technology administrators such as database and system administrators are in the second subgroup, which has a lower requirement for leadership.

The technology managers subgroup includes two job types that sometimes overlap: network and system administrators. On the basis of the skills in this analysis, network administrator jobs focus largely on network administration and internetworking various operating systems to that

Table 2

Job definitions

Job title	Job description	Major skills required
Web programmers (6,187 / 3.0%)	Generic Web development using a variety of development platforms.	HTML*, JavaScript*, Java, XML, AJAX
MS Web developers (4,297 / 2.0%)	Web development specializing in Microsoft technologies.	C/C++†, ASP*, C#*, SQL*, HTML*, JavaScript*, XML, .NET, VB
MS Web application project analysts (3,843 / 1.8%)	Application development using primarily Microsoft technologies, including some system analysis.	C/C++†, SQL†, C#*, XML, MS Databases, .NET*, ASP, VB, OOP, SDLC
Java database Web developers (6,766 / 3.2%)	Web-based database application development using Java.	Java†, JSP, SQL*, MS, XML*, HTML, JavaScript, Oracle
Open source Web application developers (3,185 / 1.5%)	Web application development using open source technologies, GUIs, and back-end development.	HTML, open source/Unix operating systems, PHP, Java, JavaScript, Perl, SQL, open source databases
Java programmers (12,380 / 5.9%)	Programming position specializing in Java and Java-related programming.	Java†, programming, software development, OOP
MS developers (7,018 / 3.3%)	Traditional development specializing in Microsoft languages with high C# requirement.	C/C++†, C#†, .NET, object-oriented programming
Open source developers (8,258 / 3.9%)	Primarily a programming position working with many languages associated with the open source community.	C/C++, Java, open source/Unix operating systems†
C/C++ programmers (12,919 / 6.2%)	Programming specializing in C/C++. Few other major skill requirements.	C/C++, programming skills†
System-level C/C++ programmers (6,485 / 3.1%)	Specialized C/C++ programming, developing applications that interface at the operating system level.	C/C++†, programming skills*, security, operating systems*, TCP/IP, Perl, Java
Database developers (14,580 / 7.0%)	Working with SQL and different database systems. Moderate amounts of programming and system analysis.	SQL†, Oracle, MS and generic databases, programming skills
Java database application developers (7,210 / 3.4%)	Development of database applications in Java. Primarily focused on using Oracle and Unix.	Java†, Oracle*, SQL*, Unix*, Perl, XML
MS Visual Basic (VB) database application developers (6,849 / 3.3%)	Development of database applications primarily using VB, .NET, and ASP.	SQL†, Microsoft databases, Visual Basic, .NET, ASP
MS database application developers (6,975 / 3.3%)	Development of database applications using Microsoft technologies. Distinguished from MS VB Database Application Developer by requirement of C#, C/C++, SQL, and ERP skills.	C#†, C/C++†, SQL†, .Microsoft databases, NET, ASP
IT managers (26,656 / 12.7%)	Includes a variety of jobs, most of which include a leadership component as well as a high frequency of non-IT-oriented business skills.	Leadership, strategy, finance, marketing, accounting, telecom, CASE tools, SCM, BPR, ERP
System administrators (15,248 / 7.3%)	Administration of end-user computing systems and workstations (primarily MS operating systems) as well as networking and telecommunications.	MS operating systems†, security, certification, networking
Network administrators (7,982 / 3.8%)	Similar to system administrators but heavier emphasis on Unix, open source, Sun, and IBM operating systems. Special focus on networking multiple technologies.	Open source†/Microsoft/Unix/IBM operating systems, security, TCP/IP, Cisco, Perl
Database administrators (8,062 / 3.8%)	Works with the administrative component of databases. Oracle stands out as the dominant database management system (DBMS).	Oracle†, Unix*, SQL, databases, ERP, data warehousing, security
Security specialists (22,813 / 10.9%)	These positions all include some security aspect but are otherwise wide-ranging.	Security†, certification, leadership
Project analysts/ managers (21,942 / 10.5%)	Project management, often including a leadership or strategy component.	Project management planning†, budgeting†, scheduling†, leadership, strategy, certification, finance, ERP, responsibility

Note: Dagger (†) indicates 90 percent+ frequency; asterisk (*) indicates 80 percent+.

Cluster Analysis

We performed a cluster analysis on the ads in two phases. Because we had no preconceived notions about the actual number of job types that the ads represented,[1] we used hierarchical agglomerative clustering in the first step to identify 20 unique skill set clusters. We used this number as input to the second step: a *k*-means cluster analysis. This technique produced the easiest-to-interpret set of clusters, had stable clusters with split samples,[2] and was unaffected by randomized input.[3]

We validated the classification of 209,655 ads into 20 clusters by again performing *k*-means cluster analysis with inputs from 5 to 50 clusters. We then calculated the mean differences to the cluster centroids for each cluster.[4] Twenty clusters produced the lowest average mean difference to the centroid. This indicated that 20 clusters had significant cohesion among the cases in those clusters, meaning that the jobs (clusters) with those skill sets were the most consistently defined. In addition, with 20 clusters, the job definitions with the smallest number of ads were already less than two percent of the total. Analyses with larger cluster numbers led to job definitions that were too small (in other words, that were too specialized) to be of practical use for most career planning.

Other researchers have criticized cluster analyses in prior studies for small sample sizes, lack of stability of the number of clusters,[2] and the effects of input order.[5] Our study used a very large sample—almost a quarter-million job ads—and had some assurance of stability by using repeated runs with random ordering. This ensured a consistent and stable number and nature of clusters. We iteratively found an average 90 percent consistency between the sets of clusters.

We then named and interpreted each cluster as an IT job type, independently evaluating the clusters, proposed names, and descriptions of the job types on the basis of the frequencies of skills in each cluster. There was 95 percent agreement in the jobs' initial names and characteristics. We achieved consensus through discussion that led to minor revisions of the names.

The results underwent a final validation to test the accuracy of the parsing software and the cluster analysis. We drew stratified random samples of job ads for each of the 20 clusters. Each author manually classified the ads into one of the 20 clusters judged to be the best fit on the basis of each ad's original text.[6] This test uncovered issues with the software, which we corrected before reanalyzing the data. The final iteration of this test (with a different random sample) found three ads that were misclassified because of limitations in the parsing software and another six that were either placed in the wrong cluster or didn't have an appropriate cluster. Neither of these types of errors seemed to affect the clustering process, and this rate has reliability similar to studies exclusively employing human judges.[7] The tests indicated that we achieved an overall successful classification rate of 91 percent, which is significantly better than comparable data-mining studies.[6]

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end. On the other hand, although system administrator jobs might incorporate some network administrator roles, they focus primarily on the administration of end-user computing systems and workstations.

Analysts are the final group in Figure 2. This group consists of the project analyst/managers cluster, which requires skills such as project management, planning, budgeting and scheduling, and leadership. This group requires project management skills uniformly through all of its job ads in contrast to the IT managers cluster, which relies more consistently on leadership skills.

As Figure 1 shows, the IT managers job type has the largest number of available jobs. Security specialists and project analysts/managers follow closely. Like the IT manager cluster, this cluster's size results from the inclusion of diverse staff with some management function. The size also indicates high demand for management skills in the marketplace. Each job in the security specialists cluster has security mentioned in its ad. Over 31 percent also listed industry certifications as requirements. The high number of ads, along with the demand for security in this cluster, indicates high demand for this skill. Considering that security is important even for common software development projects,[8] security awareness among

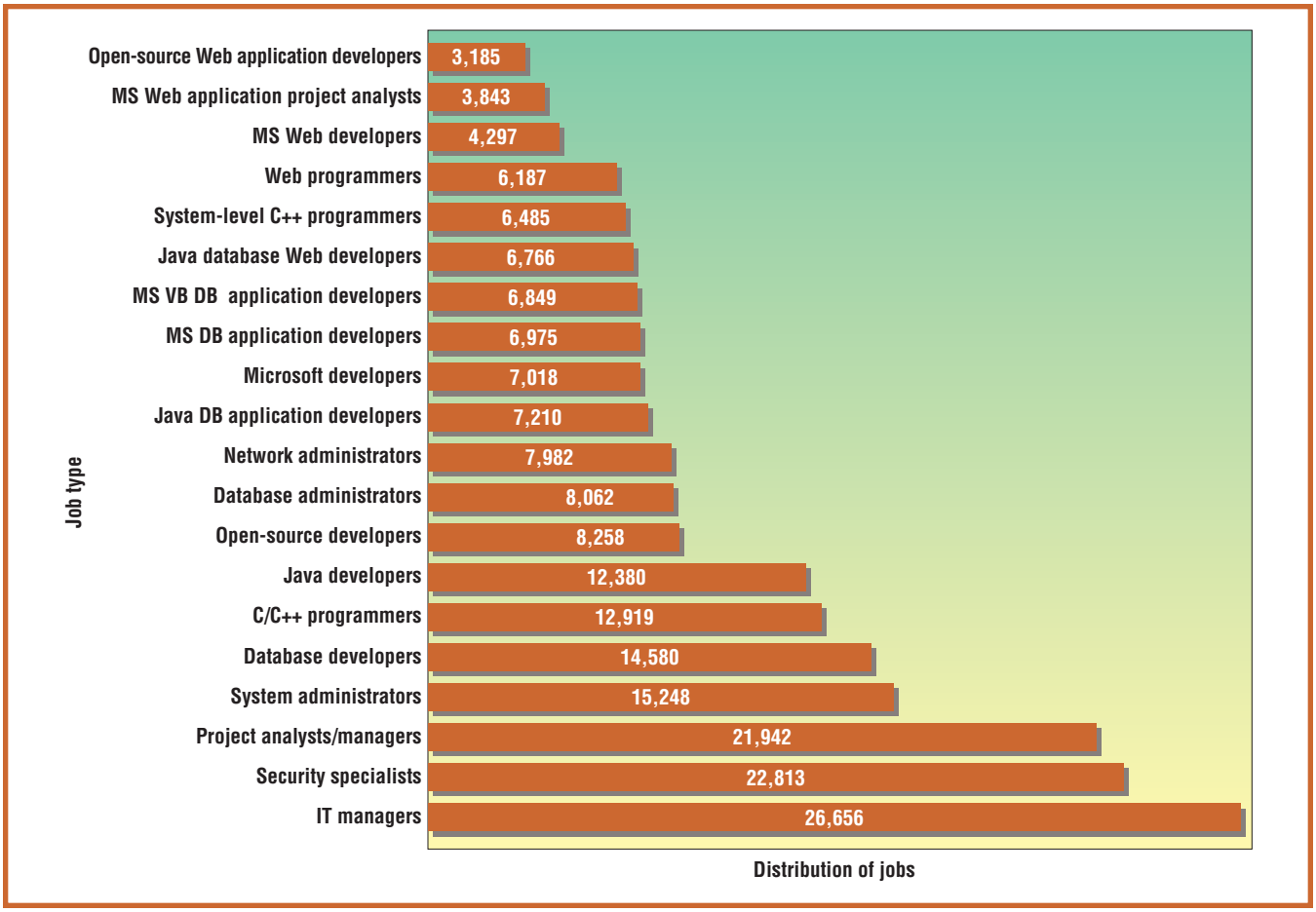

Figure 1. Distribution of jobs by job type. The figure graphically represents the relative frequency and number of job ads placed into each cluster.

employers is therefore probably leading to a new career path. Jobs in the project analysts/managers cluster demanded project management skills, closely followed by leadership. This traditional career path is still in high demand.[9]

Implications for Career Development

In any discipline, and especially in a discipline with a dynamic, highly competitive technology environment, professionals should periodically review the skills sets in high demand and identify industry trends in which their skill sets might be falling behind. Where downsizing and outsourcing is common, keeping up with current skill sets is critical.

Microsoft is a dominant presence in software. However, our research indicates that few organizations focus exclusively on Microsoft-oriented technologies. Although five of 20 clusters require skills specifically in Microsoft technologies, they account for only about 14 percent of all job ads. Open source and Java jobs are very competitively positioned, and they comprise about 12 percent of the ads. Open source technologies might soon match the demand for Microsoft technologies in terms of the number of jobs.[10] Microsoft development skills and open source skills should constitute a significant component of skill sets for both first-time job seekers and established computing professionals.

The Web developers group accounts for 12 percent of all jobs, yet when considered among all development groups, Web development jobs account for almost a quarter of all programming work. This finding highlights the surprisingly low number of jobs whose only focus is Web-based programming. Additionally, although Microsoft isn't a dominant force in overall Web development, its technologies account for a third of all such work, whereas Java and open source development account for over 40 percent. It appears that Web development is an arena without a dominant technology but rather with focused niches from all platforms and that many different skills are marketable in this arena.

In the database administrators cluster, 91 percent of all jobs require Oracle. There's no corresponding cluster with such a high preference for any other database management system. The strong preference for Oracle skills is significant for computing professionals' career planning.

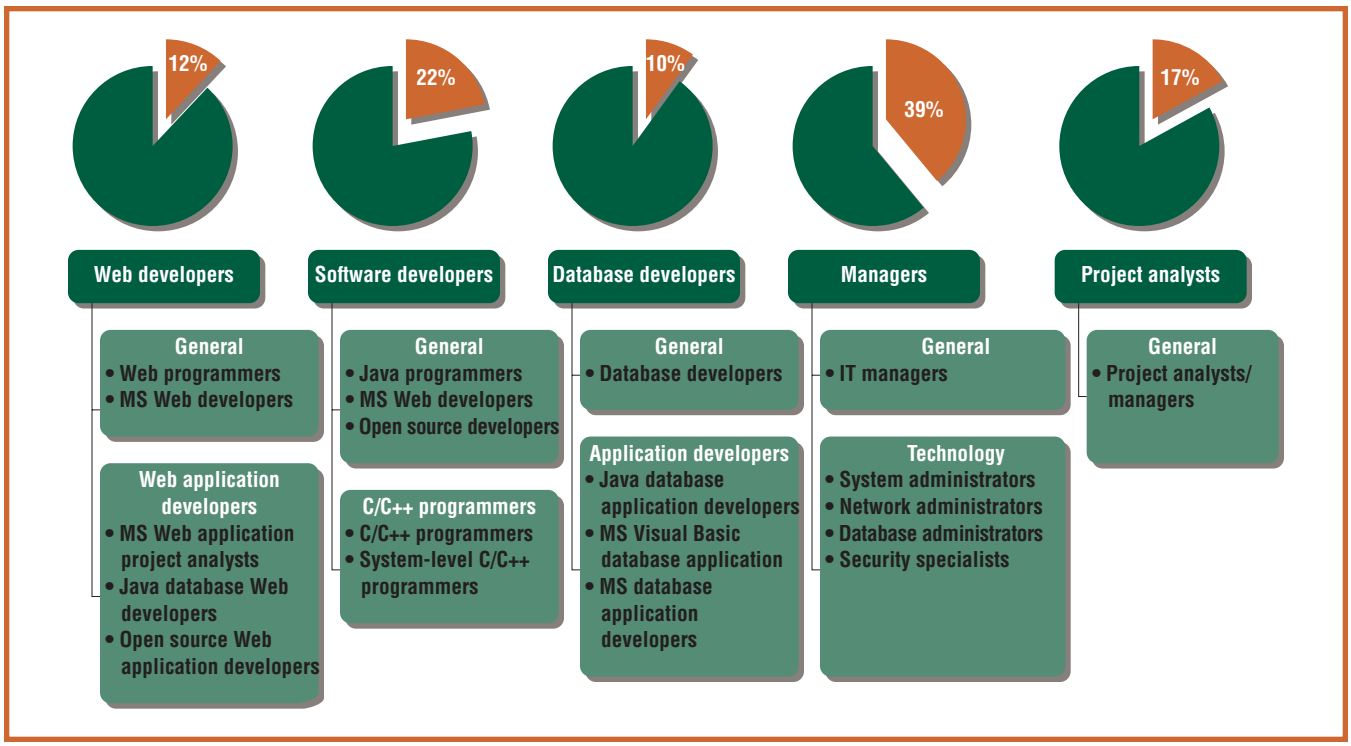

Figure 2. Types of information technology jobs. The figure shows the five groups of clusters, the job types in each group, and the relative distribution of job ads for those groups.

Implications for Organizations

From the 1970s through the 1990s, the programmer's role expanded to include not only technical programming but also an increasing knowledge of business, communication skills, and critical thinking.[11] The programmer became a programmer/analyst. Through 2003, programmer/analyst was the job term occurring most frequently in job ads.[12] In a study of ads placed online between 2001 and 2003, ads for programmer/analysts specifically requested skills in software development and software (98 percent), but also business (83 percent), social (83 percent), problem-solving (77 percent), management (67 percent), architecture/network (67 percent), and hardware (42 percent) skills.[13]

Our study determined job titles composed of collections of skill sets that appeared together in online ads. The results indicate that a split is occurring between programmer jobs and analyst jobs. There are three different developer job types: Web, software, and database developer. Each leans heavily on technical skills. The other two job types, managers and project analysts, have more general technical skills but also include skills such as leadership, strategy, and security.

Development jobs requiring considerable technical knowledge but needing relatively little business or management knowledge are more easily outsourced than jobs requiring a great deal of business domain knowledge. Perhaps organizations are consciously or unconsciously preparing to outsource more development jobs by separating the programmer from the analyst. This has clear implications to people seeking to upgrade their skill sets. For organizations, this result might indicate where the industry is headed, and they might wish to prepare accordingly.

Our study is constrained by the data sources we mined. Although since 2006 employers have placed most US job ads online[14] and offline or print ads are often replicated online,[15] we can't incorporate ads that are exclusively in print into the data collection. However, because print ads have space constraints that aren't imposed on online ads, they can't be as comprehensive in listing needed skills as online ads. So, not including print ads could improve our results. Our data sources included only ads for the US national job market. Future research could also incorporate international job ads.

Our analysis focuses on a snapshot of the current job market and doesn't attempt to predict the future skills industry might need, or even show which skills might be becoming more or less popular. Although there's a significant amount of prior research in this area, the number of skills that the current research methodology covers is far greater than previous research, so we can't reliably accomplish trend analysis across these very different tech-

niques. However, as more research uses these information extraction techniques, it will be possible to track past and future trends in skill popularity, job availability, and shifts in skill combinations.

This article has statistically grouped related computing job ads into consistent job definitions based on current skill sets for the first time. Human resource managers and IT managers can take these job definitions as a set of widely used US jobs they can contrast with their organizations' job definitions to better word their own job ads. More-standardized job titles and skill requirements will improve employers' abilities to find and correctly place needed employees. Similarly, educators might use these job definitions to identify the necessary skills for their graduates to sustain a growing economy and continued expansion of computing jobs.[9] Students can also use them to plan which courses they should take to get the job they desire.

This article can serve as a baseline for future research because it quantifies the current relative frequency of specific skills in job definitions. As time passes, we expect job definitions to change and emerging technologies to replace older technologies. Documenting this trend should provide an interesting timeline for the evolution of the computing field. Once more data has been collected, it will also be useful to compare the differences between the skill requirements for graduates of different computing degree programs to help students and industry understand the differences among computer science, management information systems, and IT degrees.

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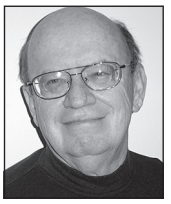

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