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Architecting Out Software Intellectual Property Lock-In: A Method to Advance the Efficacy of BBP

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Panel 6. Considerations in Software Modeling and Design

Wednesday, May 4, 2016	
1:45 p.m. – 3:15 p.m.	**Chair: John Zangardi,** Deputy Assistant Secretary of the Navy for Command, Control, Communications, Computers, Intelligence, Information Operations, and Space ***Achieving Better Buying Power for Mobile Open Architecture Software Systems Through Diverse Acquisition Scenarios*** Walt Scacchi, Senior Research Scientist, Institute for Software Research, UC Irvine Thomas Alspaugh, Project Scientist, Institute for Software Research, UC Irvine ***Architecting Out Software Intellectual Property Lock-In: A Method to Advance the Efficacy of BBP*** Maj Chris Berardi, USAF; Bruce Cameron, Lecturer, MIT; Daniel Sturtevant, CEO, Silverthread, Inc.; Carliss Baldwin, Professor, Harvard Business School; and Edward Crawley, Professor, MIT ***Navy Mobile Apps Acquisition: Doing It in Weeks, Not Months or Years*** Jacob Aplanalp, Assistant Program Manager, My Navy Portal, PEO EIS; Dave Driegert, Senior Technical Advisor, PEO EIS; Kevin Burnett, Technical Manager, PEO EIS; and Kenneth Johnson, Technical Director, PEO EIS

Architecting Out Software Intellectual Property Lock-In: A Method to Advance the Efficacy of BBP

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Abstract

This paper works to understand Department of Defense (DoD) contracting trends since the beginning of Better Buying Power (BBP). By using data publicly available from the Governmentwide Point of Entry (GPE), this paper concludes that there are no clear trends in the levels of competition in the DoD, as measured by ratios of Justifications and Approvals (J&A) to contract awards, as a result of BBP. However, this is not to say that BBP is ineffectual, but that methodologies are still needed to implement the guidance outlined in BBP. To that end, this paper proposes a methodology to identify salient data rights in computer software. Our aim is to provide a means for program managers to understand which data rights are most important to ensure future sustained competition.

Introduction

Over five years have passed since the first version of Better Buying Power (BBP) was introduced by Secretary of Defense Aston Carter, formerly Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]; Carter, 2010). In that time, two updated versions of BBP were released by the current USD(AT&L) Frank Kendall: BBP 2.0 (Kendall, 2013) and BBP 3.0 (Kendall, 2015). Since the initial BBP, many authors offered critiques of the BBP strategies (examples include Hasik, 2014; Hill, 2013; Huitink, 2014; Hunte et al., 2015; Layden & Arndt, 2012) with varying sentiments of approval or disapproval. However, within these critiques are two reoccurring patterns. First, the majority of critiques are made using qualitative methods. These analyses are important, but represent a somewhat one-sided story without any accompanying quantitative analyses.

Second, many lament that BBP is akin to a management philosophy that lacks any insight into implementation, but very few critics offer methods to aid in implementation. One example is Hasik's (2014) review, "Carter effectively introduced a slew of new rules into the Pentagon's bureaucracy, but he and his successor have developed few mechanisms for affecting the behavioral change beyond issuing a memorandum" (p. 17).

Consequently, our work herein endeavors to serve two purposes. First, to analyze data from the Governmentwide Point of Entry[1] (GPE) to identify any trends in levels of DoD competition since the introduction of BBP. We will not, however, tread into complicated tests of statistical significance with the hope of identifying minute changes in competition. Rather, our goal is to look for broad changes in DoD competition patterns, after which we will devote the second half of this paper to explain a methodological approach to aid in the realization of three BBP initiatives.

State of Competition

The 2015 Annual Report of the *Performance of the Defense Acquisition System*, released annually by the office of the USD(AT&L), argues that competition is starting to rise. To substantiate this statement, the report uses a fractional measure of contracts competitively awarded by dollar amount. The most recent measures show that 58.3% of fiscal year (FY) 14 contracts, by dollar amount, were competitively awarded, which is up from 57% in FY13 (USD[AT&L], 2015). However, this methodology is sensitive to an outlier bias, where a few large contracts awarded competitively (i.e., contracts on the order of magnitude in the $100s of millions) overshadow the many smaller contracts awarded using other than full and open methods. In this scenario, there may be competition amongst a small number of large contractors on big contracts, but little to no competition amongst the many hundreds, if not thousands, of contractors on the small contracts. This results in metrics that reflect a large quantity of competition by dollar amount, but little change in the actual number of competitive contracts awarded. Unfortunately, no methods were used to control for this bias in either the quantitative analysis or the interpretation of results. We make no argument that the data presented by the USD(AT&L) is overestimated or underestimated, only that more analyses are needed to triangulate the actual effects.

Given these methodological choices, it is difficult to determine, with any certainty, whether competition in DoD contracts is increasing or decreasing. This makes determining the efficacy of BBP equally difficult. Consequently, we propose an independent study using data from the GPE to triangulate the results in the 2015 *Performance of the Defense Acquisitions System* report. The GPE is an online repository for U.S. Government business opportunities, which is accessible by the public. This is an ideal source of data because DoD agencies are required by Federal Acquisition Regulation (FAR) 5.201 to post synopses of contracting actions above $25,000.[2] Furthermore, the contract notices on the GPE cover the

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[1] "Governmentwide point of entry (GPE) means the single point where Government business opportunities greater than $25,000, including synopses of proposed contract actions, solicitations, and associated information, can be accessed electronically by the public. The GPE is located at http://www.fedbizopps.gov" (48 CFR 2.101—Definitions).

[2] FAR 5.202(a) outlines 14 exceptions to the mandatory contract synopsis policy outlined in 5.201. The exceptions are too lengthy to enumerate in detail herein; however, the 14 exceptions are sufficiently specific to ensure the maximum amount of information is available to the public.

spectrum from a vehicle maintenance contract at an Air Force base in South Dakota in the tens of thousands of dollars to ACAT-type programs in the tens of millions of dollars. From these posted contract notices, we can quantify the overall DoD procurement activity per fiscal year.

In addition to contract notices, other types of contracting actions are also posted. Of particular interest are Justifications and Approvals (J&A),[3] which is a document released to the public when the DoD uses a procurement strategy other than full and open competition.[4] The February 17, 2009, revision of FAR 6.302 mandated that all J&A documents are posted to the public.[5] Each J&A notice on the GPE is an artifact which reflects a lack of competition in DoD acquisition. Consequently, the frequency of J&As relative the overall number of contract awards provides a separate indicator of competitiveness within the DoD marketplace that is not sensitive to outlier bias.

Data Collection

Although the data is electronically available to the public, it is made available through a web interface. Consequently, to retrieve the data a web scraper was built, tested, and employed to obtain the data for all DoD-related agencies. These agencies and their respective number of contract notices on the GPE are outlined in Table 1.

Web scraping is a time-consuming process which is costly to both the provider of information, in terms of increased website traffic, and the scraper, in terms of bandwidth and data size. In an effort to minimize the impact of scraping, only seven variables were collected for each notice posted on the GPE: name, contract number, class code, agency, procurement organization (within the agency), date of notice, type of notice, and the URL for each specific notice page.

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[3] "Justification and Approval (J&A) is a document required to justify and obtain appropriate level approvals to contract without providing for full and open competition as required by the Federal Acquisition Regulation (FAR)" (Defense Acquisition University, 2015).

[4] For those unfamiliar with DoD jargon, "other than full and open competition" is defined as any sole source or limited competition contract action that does not provide an opportunity for all responsible sources to submit proposals.

[5] Similar to the FAR 5.202(a) exception, there are also exceptions for Justifications and Approvals outlined in FAR 6.305(b) and (c).

Table 1. Number of Notices Collected by Agency

AGENCY	NOTICES
DEFENSE LOGISTICS AGENCY	675,041
DEPARTMENT OF AIR FORCE	219,025
DEPARTMENT OF ARMY	322,139
DEPARTMENT OF NAVY	274,984
OTHER DEFENSE AGENCIES[6]	27,756
TOTAL	1,518,945

In addition to the approximately 1.5 million contract notices collected, additional details specific to each J&A were also scraped. Similar to the contract notices, the scraping only gathered a parsimonious collection of variables for each J&A: name, contract number, contract award date, FAR authority, service, command, program management office, classification code, and North American Industry Classification System (NAICS) code. The results of this secondary scrape are outlined in Table 2.

To control for threats to internal validity from instrumentation error, the total number of notices was cross checked against the number displayed on the GPE. In all cases, the number of notices collected by the web scraper match the number of entries in the GPE archive. This ensures no portion of the data was errantly omitted from the sample. Additionally, to control for lagging policy effects caused by the February 17, 2009, revision of the FAR, which mandated J&A public disclosure, all data before FY10 was omitted. The resulting data covers FY10–FY15. Additionally, three contract notices contained dates with years greater than 2016, and 66 of the J&As did not contain a FAR authorization. These data were excluded from the final sample analyzed below.

Data Analysis

There is some seasonality in both the contract award and J&A data, which is centered around the end of each fiscal year, see Figure 1(a). This result is expected, given the race to obligate funds before the end of the fiscal year. However, what is unexpected is the difference in seasonality between contract awards and J&As in both FY12 and FY13 (see Figure 1(a)). This phenomenon is most likely explained by the Budget Control Act of 2011, commonly referred to as "sequestration," which required nine annual sequesters of $109 billion. The first of the annual sequesters took effect in March 2013 (Van Hollen, 2015), likely stymying the number of contracts awarded both before and after. Interestingly, there appears to be no sequestration effect on the number of J&As during the same time periods. Additionally, we see no substantive reduction in the absolute number of J&As in the six fiscal years under study.

We also considered the fraction of J&As relative to contracts awarded (see Figure 1(b)). This measure shows a ratio of uncompetitive contracts to competitive contracts. In this

[6] Examples of Other Defense Agencies include: Defense Advanced Research Projects Agency (DARPA), Uniformed Services University of the Health Sciences (USUHS), U.S. Special Operations Command (SOCOM), Department of Defense Education Activity (DoDEA), Defense Commissary Agency (DCA), United States Transportation Command (TRANSCOM), Defense Finance and Accounting Service (DFAS), etc.

data we see spikes in the fractional measure at the end of FY11 and during FY13. As previously discussed, the FY13 numbers are most likely explained by sequestration. However, the spike during the initial quarter of FY12 appears to be a result of low number of contracts awarded. In fact, the contract awards during the first quarter of FY12 are the lowest out of any quarter between FY10–FY15. This is likely explained by the five successive Continuing Resolutions appropriations in FY12. Interestingly, there seems to be no obvious connection between the introduction of BBP initiatives[7] and the fraction of J&As to contract awards. If we look at the six-month exponentially weighted moving average (EWMA) of the fractional measure, we see that even after three iterations of BBP DoD levels of competition are similar. This is not to suggest that BBP was ineffectual or that there was no impact on competition, but that no obvious conclusion can be made based on the data in the GPE.

Lastly, we examined a moving cross correlation between contract awards and J&As (see Figure 1(c)). The data have a static correlation of 0.55 $(p = 5.9e-7)$. Furthermore, for the large majority of the months spanning FY10–FY15, there is a positive six-month moving cross correlation, sometimes as high as 0.96. As with Figures 1(a) and 1(b), there is some variability in the outcomes, but those are largely explained as lagging effects from the events previously discussed. We believe this to be an important measure of competition because if competition rates were truly improving, we would expect to see the correlation between contract awards and J&A move closer to 0, or no effect. While the data from the GPE do demonstrate some periods of no correlation between J&A and contract awards, 94% of the points in the sample have a positive six-month moving cross correlation.

[7] BBP initiatives are dated using the stamp dates from the USD(AT&L) memorandums which directed implementation. The respective dates are as follows: BBP 1.0—June 28, 2010; BBP 2.—April 24, 2013; and BBP 3.0—April 9, 2015.

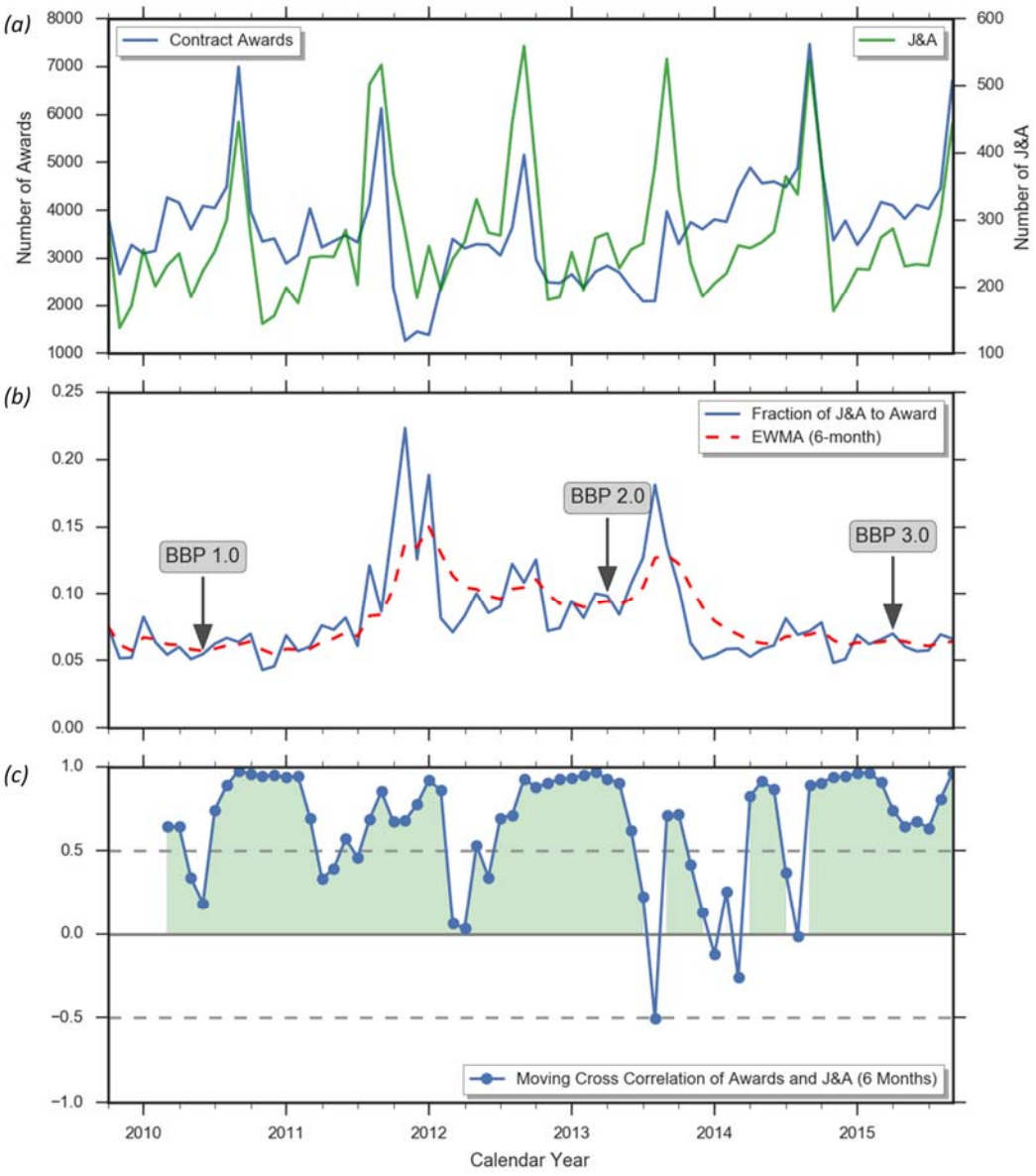

Figure 1. Contract Awards and J&As

Note. All subplots in Figure 1 are drawn using a calendar year x-axis, not a U.S. Government Fiscal Year x-axis. (a) Shows the frequency of contract awards (left y-axis) and J&As (right y-axis) as a time series sampled on a monthly frequency. (b) Shows the fraction of J&A to contract awards. Callouts on (b) denote when each of the three versions of BBP were mandated by USD(AT&L). To remove some seasonality from the fraction, the red dashed line shows a six-month exponentially weighted moving average (EWMA). (c) Shows a six-month moving cross correlation between contract awards and J&As.

Discussion

The aforementioned results do not demonstrate any facts with statistical certainty; however, they do illustrate that the data are noisy and influenced by multiple exogenous events. Additionally, the independent analysis of GPE data do not necessarily support the clear-cut conclusions in the 2015 edition of the *Performance of the Defense Acquisition System* report. The numbers may be improving by proportion of dollars competitively

awarded, but an examination of the frequency of uncompetitive contracts to competitive contracts shows no clear improvement.

Those familiar with J&As and FAR Part 6 will rightly point out that not all J&As are equal in their ability to indicate a lack of competition. This is true; there are seven different categories of J&As (the GPE uses eight categories, adding a subcategory for 6.302-1). Table 2 enumerates the different types of J&As and their frequency in the GPE during the period FY10–FY15.

Table 2. GPE Justifications and Authorization Types and Respective Frequency

J&A AUTHORIZATION	COUNT
FAR 6.302-1 - *Only One Responsible Source (Except Brand Name)*	13,922
FAR 6.302-1(C) - *Brand Name*	2,155
FAR 6.302-2 - *Unusual and Compelling Urgency*	1,748
FAR 6.302-3 - *Industrial Mobilization; Engineering, Developmental or Research Capability; or Expert Services*	138
FAR 6.302-4 - *International Agreement*	59
FAR 6.302-5 - *Authorized or Required by Statute*	607
FAR 6.302-6 - *National Security*	5
FAR 6.302-7 - *Public Interest*	671
TOTAL	19,305

The J&A authorized by FAR 6.302-2 is for other than full and open competition in cases of "unusual and compelling urgency." This category does not accurately reflect the DoD's inability to implement a competitive process, but a choice to exclude competition in the interest of exigent circumstances. This same argument could be made for all J&A types, except FAR 6.302-1. However, FAR 6.302-1 is by far the most prevalent type of J&A, accounting for approximately 83% of all the J&As in the GPE (see Figure 2(a)). Across FY10–FY15 we see that the average rate of 6.302-1 J&As is approximately 83%, with the percentage trending somewhat higher in FY12 and FY13. Consequently, it is safe to argue that 6.302-1 J&As are by far the most frequently used across the fiscal years examined and that by removing the remaining 17% from the sample would only have a marginal effect on the analyses presented in Figure 1, as the ratio of 6.302-1 J&As removed would be nearly uniform for each fiscal year. Interestingly Figure 2(a) does not show any trends in J&A type, as a percentage of total number, across six fiscal years. Prior to this analysis we hypothesized that the impact of BBP (1.0–3.0) would have had some noticeable impact on the quantity and type of J&As used. From the data presented in Figure 1 and Figure 2, there are no easily observable results that would support this hypothesis.

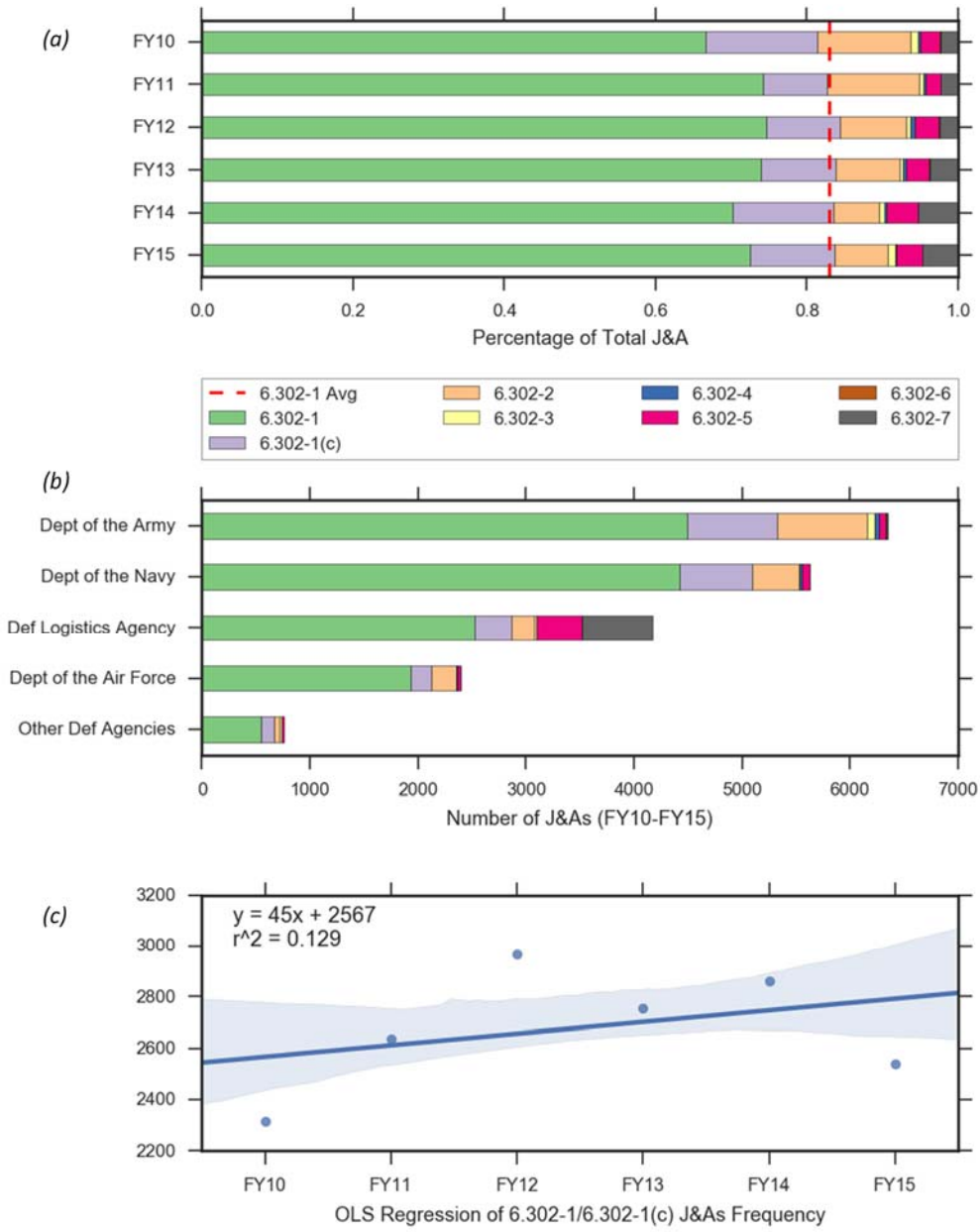

Figure 2. J&As Data

Note. All subplots in this figure have different x axes, which differs from Figure 1 which used a common x axis. (a) Depicts the percentage of each J&A type by fiscal year. The dashed red line shows the average number of 6.302-1 and 6.302-1(c) J&As across all fiscal years. (b) Depicts the total number of each J&A type by service from FY10 through FY15. (c) OLS regression of the total number of 6.302-1 and 6.302-1(c) J&As from FY10 through FY15. Although FY15 showed a reduction in 6.302-1 and 6.302-1(c) J&As, the overall trend is slightly positive with a coefficient of 45 and an intercept of 2,567. The shaded area represents a confidence interval of 58, which corresponds with the standard error of the estimate.

The nature of the information stored in the GPE allows us to also understand which Service is generating the most 6.302-1 J&As (see Figure 2(b)). Prior to undergoing this analysis, we hypothesized that all services would be roughly equal in the number of J&As. However, the data at Figure 2(b) illustrate a different picture. For the sample period

examined the Army and Navy are, by a large margin, the biggest producers of 6.302-1 J&As (e.g., the Army generated approximately 150% more 6.302-1 J&As than the Air Force in the sample period). However, it is important to remind the reader that these numbers do not control for the size, in terms of dollars, of each J&A. As a somewhat hyperbolic example, each of the Air Force's J&As could be for a $1 billion space system and the Army's J&As could be for a $1,000 rifle. Therefore, there are limitations on the conclusions which can be drawn from the data outlined in Figure 2(b). Also interesting, the Defense Logistics Agency seems to be the sole user of the FAR 6.302-7, Public Interest, J&A, accounting for 97% of all the 6.302-7 J&As issued across six fiscal years. Given the universal nature of the FAR, we did not expect one service to dominate the use of a particular type of J&A.

The J&A data thus far demonstrates that 6.302-1 is the most prevalent type as a percentage of the total number of J&As, but is there a trend in the use of 6.302-1 J&As across the fiscal years in the sample? To address this question, we fit an Ordinary Least Squares (OLS) regression to the number of 6.302-1 J&As across the six fiscal years under examination (see Figure 2(c)). Given the small number of samples the OLS regression model would not be useful as a predictor of future values of 6.302-1 J&As; however, it is a rough indicator of a positive trend in the number of 6.302-1 J&As. If the levels of competition, measured as number of contracts competed, were increasing, we would expect a negative or downward trend in the number of 6.302-1 J&As over the sample period. That being said, the standard error for the OLS estimator is 58, which indicates it is possible, but perhaps not probable, that there is a slightly negative trend in the data.

Given that we now know 6.302-1 is the most prevalent type of J&A and that 6.302-1 use is likely increasing, it is worth discussing this specific FAR authorization in more detail. The FAR does not enumerate all possible uses of 6.302-1, but it does provide guidance on application of the regulation. In doing so, it provides four situations in which the authority in 6.302-1 may be appropriate. It is important to note that this list is not intended to be all inclusive. These four situations are as follows:

> (1) When there is a reasonable basis to conclude that the agency's minimum needs can only be satisfied by —
>
> (i) Unique supplies or services available from only one source or only one supplier with unique capabilities; or,
>
> (ii) For DoD, NASA, and the Coast Guard, unique supplies or services available from only one or a limited number of sources or from only one or a limited number of suppliers with unique capabilities.
>
> (2) The existence of limited rights in data, patent rights, copyrights, or secret processes; the control of basic raw material; or similar circumstances, make the supplies and services available from only one source (however, the mere existence of such rights or circumstances does not in and of itself justify the use of these authorities) (see Part 27).
>
> (3) When acquiring utility services (see 41.101), circumstances may dictate that only one supplier can furnish the service (see 41.202); or when the contemplated contract is for construction of a part of a utility system and the utility company itself is the only source available to work on the system.
>
> (4) When the agency head has determined in accordance with the agency's standardization program that only specified makes and models of technical equipment and parts will satisfy the agency's needs for

additional units or replacement items, and only one source is available. (FAR 6.302-1(b))

These four situations are relatively generic with the exception of 6.302-1(b)(2) and 6.302-1(b)(3), the former of which governs the application of 6.302-1 for situations where intellectual property issues or data rights limit competition, and the ladder towards a narrow situation where utility services are acquired. These guiding situations pose an interesting question: Are there certain categories of goods or services for which 6.302-1 is used more frequently than others given the specificity in 6.302-1(b)(2)? To obtain an approximate measure of this we examine the procurement classification codes[8] of each 6.302-1 J&A. These are considered an approximate measure, as the contracting official has final authority on which procurement classification code the J&A will use; therefore, there is some variance in which types of effort fall into which procurement classification code. Consequently, the GPE encourages interested bidders to search across similar classification codes (e.g., a bidder interested in *15–Aircraft and Airframe Structural Components* should also search in *16–Aircraft Components and Accessories*). However, unless the two codes are similar in domain or type then the procurement classification codes provide a good guideline (i.e., it would be difficult to argue there is overlap between *24–Tractors* and *14–Guided Missiles*). Table 3 outlines the top 10 Product Service Codes (PSC) and Federal Supply Codes (FSC) by number of 6.302-1 J&As.

Table 3. Top 10 Product Service Codes (PSC) and Federal Supply Codes (FSC) by 6.302-1 J&A

Products	Count	Services	Count
16 -- Aircraft components & accessories	1,720	R -- Professional, administrative, and management support services	981
70 -- General purpose IT equipment	1,107	Q -- Medical services	920
20 -- Ship and marine equipment	725	D -- Information technology services, including telecommunications services	813
58 -- Communication, detection, & coherent radiation equipment	666	J -- Maintenance, repair & rebuilding of equipment	677
65 -- Medical, dental, veterinary equipment & supplies	611	A -- Research & Development	339
15 -- Aircraft & airframe structural components	560	S -- Utilities and housekeeping services	297
59 -- Electrical and electronic equipment components	525	U -- Education & training services	197
99 -- Miscellaneous	506	V -- Transportation, travel, & relocation services	142
66 -- Instruments & laboratory equip	463	Z -- Maintenance, repair, and alteration of real property	136
28 -- Engines, turbines & components	326	L -- Technical representative services	100

[8] Procurement classification codes are truncated versions of both the Federal Supply Codes (FSC) and Product Services Codes (PSC). For example, instead of using the four-digit Federal Supply Code 1620–*Aircraft Landing Gear Components*, the procurement classification code uses only the first two digits *16–Aircraft Components and Accessories*.

Table 3 shows some interesting patterns in the type of goods and services procured using 6.302-1 J&As, namely the largest number of product J&As belongs primarily to aircraft related PSCs (16,15, and 28) and the second most appears to be electronic equipment PSCs (70, 58, 59, and 66). Viewing these results under a Williamsonian Transactional Cost Economics lens, these results are somewhat intuitive based on the language in FAR 6.302-1(b)(2). Products with a high asset specificity are expected to carry some mode of safeguard, in this instance, intellectual property protection to defend against transactional hazards (Williamson, 1981). Said differently, products built specifically for a single purpose with little opportunity for dual-use in the commercial market (e.g., aircraft landing gear on a F-16 or IT equipment designed to process UAV full motion video) are expected to carry intellectual property safeguards to protect the manufacturers' ideas and investments. Failure to protect such intellectual property would lead to a situation where competitors could easily reproduce the original manufacturer's goods, a transactional hazard. Therefore, we can expect these types of products are often procured under a 6.302-1 J&A. Although not a revelatory conclusion, this loose connection between intellectual property and 6.302-1 J&As adds credence to many of the intended changes suggested in BBP.

Improving Competition

The most recent iteration of Better Buying Power, BBP 3.0, outlines three strategies which confront the issue of intellectual property in DoD procurement. The first, *Remove Barriers to Commercial Technology Utilization,* argues that the DoD should capture private sector innovation by using commercially available technologies and products, but directs further analysis of the implications on intellectual property. The second strategy, *Increase the Productivity of Corporate Independent Research and Development (IRAD),* targets the misuse of IRAD funds by defense contractor on "*de minimis* investments primarily intended to create intellectual property" (Kendall, 2015) to secure a competitive advantage in future DoD contracts. The final strategy, *Use Modular Open Systems Architecture to Stimulate Innovation*, argues that the DoD must control relevant interfaces to ensure competitors with superior products are not occluded from competition due to intellectual property restricted interfaces.

The commonality across these three strategies is the management of intellectual property. This is not a new concept in DoD procurement. In fact, there is a statutory requirement for the DoD to manage intellectual property in the John Warner National Defense Authorization Act for Fiscal Year 2007, which "require[s] program managers for major weapon systems and subsystems of major weapon systems to assess the long-term technical data needs of such systems and subsystems and establish corresponding acquisition strategies that provide for technical data rights needed to sustain such systems and subsystems over their life cycle" (Mazour, 2009, citing 10 U.S.C. § 2320(e)). This is a difficult statute to comply with because it asks members of the DoD acquisition community to predict what data rights are needed in the future. Being that there is no readily agreed upon method for accomplishing data rights forecasting, Eli Mazour (2009), in his article *for Public Contract Law Journal*, correctly points out that the easiest way to comply with this law "is to acquire as many rights as possible in as much technical data possible" (p. 681). The logic being, if one acquires all possible data rights, then one is certainly prepared to sustain a weapon system over its life cycle. Mazour's comments are illustrative of the problem with both statutory requirements and with the BBP strategies; neither offer a means for program managers to accomplish what is required. This brings us to a major question confounding the DoD procurement community—how do program managers determine which data rights to purchase?

In the second half of this paper we endeavor to provide a means for understanding intellectual property in computer software and determining which data rights should be purchased to increase the likelihood of sustained future competition. The choice of software, versus a physical system (e.g., aircraft components), is critical for three reasons. First, our analyses of J&As herein identifies electronic equipment, which all host software, as an area where items are often procured using other than full and open competition. Second, the increased DoD emphasis on acquiring open source software and open architectures is driving the acquisition of software systems with a complex web of open source and closed source intellectual property regimes (Carter, 2010; Kendall, 2013, 2015). Understanding the interactions between these vastly different intellectual property regimes is instrumental for future policy decisions. Third, there is a steady increase in the functions performed by software in major DoD weapon systems. Consider the juxtaposition of two generations of aircraft: In 1970s aircraft (e.g., F-111), around 20% of its functions were performed by software, whereas for aircraft in the early 2000s (e.g., F-22), 80% of its functions are performed by software (Ferguson, 2001). The role of software and the intellectual property of software are becoming increasingly important across all future DoD acquisitions.

Intellectual Property Lock-In

Before discussing our methods in detail, it is important to understand the intellectual property mechanisms that prevent competition. Specifically, *intellectual property lock-in* occurs "when switching costs outweigh the benefit of adopting a superior new product [and] a consumer is locked in to her incumbent supplier" (Breuhan, 1997, p. 2). This switching cost could be the cost of a new product itself, the redesign of a system, or the licensing costs of any new intellectual property. Described in a narrative manner, lock-in often occurs when companies vie for a share in a new market. In this situation, companies compete hard for early adopters in a given technology, oftentimes with penetration pricing (Farrell & Klemperer, 2007). An organization becomes locked-in when the cost of switching to another technology outweighs the benefit of adopting a superior, sometimes cheaper, product.

Taking it one step further, the concept of switching costs is based on the substitutability of a new technology or component. If a new piece of technology is easily substitutable, in terms of time and money, into a legacy system, then we argue there is a relatively low switching cost. Conversely, if a piece of technology is not easily substitutable, we argue that with this lack of substitutability comes a high switching cost and subsequently a high potential for lock-in. What defines intellectual property lock-in, as opposed to technological lock-in, are switching costs determined by rights to intellectual property (defined in the DoD lexicon as "data rights").

Previous work on the evolution of software design and modularity provide a means to assess the substitutability of files in software with little *a priori* knowledge on the functionality of the software itself (MacCormack, Rusnak, & Baldwin, 2007). This work builds from previous theory on the architectural design (Baldwin & Clark, 2000) and research on quantifying modularity in software (MacCormack, Rusnak, & Baldwin, 2006). Specifically, previous work studied the evolution of software over a series of sequential versions to identify the most important factors in component survival, "which is an indicator of the degree to which components can be removed or substituted" (MacCormack et al., 2007, p. 4) and shows that tightly-coupled components have a higher probability of survival as software evolves, making them "harder-to-kill." Since this measure of hardness-to-kill is a proximal measure for substitutability, it should also serve to identify those components which have high switching costs and, ergo, a large potential for lock-in.

Method

Our selected method applies a Design Structure Matrix (DSM) approach to analyze the relationships between different entities in a software system. The basic approach relies on the following four steps (MacCormack et al., 2006, 2007):

1. Capture a network representation of software source-code using dependency extraction tools.
2. Find all the paths (direct and indirect) between files in the network by computing transitive closure.
3. Calculate visibility scores to each file, which represent a file's reachability from other files or ability to reach other files in the network.
4. Organize files into one of four canonical groups based on visibility scores.

We will enumerate the basics of each step beginning with network extraction. There are two basic choices regarding the application of DSMs to software: (1) the level of unit analyzed, and (2) the type of dependency between units. Regarding the unit analyzed, it is possible to analyze software at the directory, source file, and function levels. In this methodological approach the source file is used as the unit of analysis, which is also supported by prior work on software design (Cataldo et al., 2006; Eick, Graves, & Karr, 2001; Sturtevant, 2013). There are also choices in the dependency type between these source files. Keeping with previous literature (MacCormack et al., 2006; Rusovan, Lawford, & Parnas, 2007) we use the function call. A function call is an instruction in the software code that requests a specific task be executed, sometimes making the request internally or of another source file. When one source file executes a function call that requests a task to be completed by another source file, we characterize this as a directional dependency between the two source files. For example, if a function call in file X calls a function call in file Z, we would say that file X depends on file Z. It is important to note that this is a directional dependency and just because file X depends on file Z, it does not imply file Z depends on file Z. This first order dependency extraction is accomplished using a commercial call extractor, specifically *SciTools Understand*.[9]

To illustrate the output of step 1 and the process of step 2, we point your attention to Figure 3. In this toy example we have extracted the dependencies from a piece of software that contains four source files (i.e., D, C, A, and B). Upon completing the extraction, we see that D calls C and C calls both A and D. This is a direct, or level 1, connection between the files. The resulting DSM is an illustration of the same connections in the network graph, except arrayed as a matrix. The DSM is read from right to left. For example, starting at row C from left to right, we see that two blue dots denote file C is connected to both A and B. The next step in the methodology calls for identifying all the direct and indirect paths through the software. This full set of paths is known as visibility or transitive closure. To identify the visibility of each source file we use matrix multiplication.[10] Specifically, by raising the DSM to successive powers of n, we obtain the direct and indirect dependences that exist for each successive path length n. Summing these n matrices yields the visibility matrix, which shows both direct and indirect dependencies between source files for all possible path lengths up

[9] See www.scitools.com for more details.

[10] Note that we choose to include the matrix for n = 0 when deriving the visibility matrix, implying that an element will always depend on itself.

to the maximum. If we draw our attention to the visibility matrix in Figure 3, we now see two new entries for source file D. This is because file D originally connected to file C, but file C also connected to files A and B. Therefore, in the visibility matrix we have captured this second order connection between D to A and D to B.

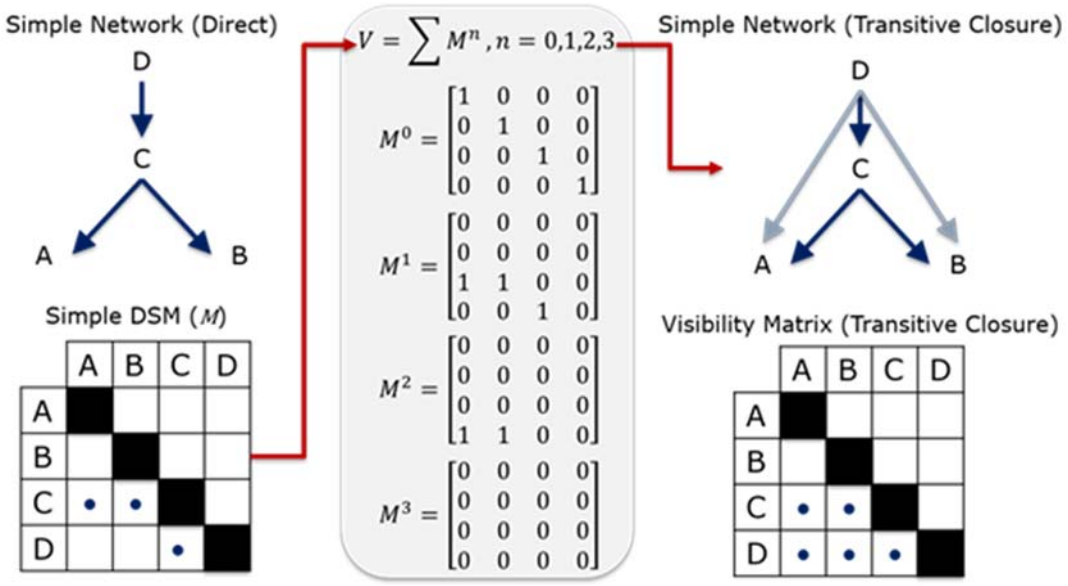

Figure 3. Example Level 1 DSM, Example Transitive Closure Calculations, and Example Visibility Matrix

The penultimate step is to calculate the visibility scores for each file in the software. The measures of visibility are derived directly from the visibility matrix (Figure 4 uses the same visibility matrix from Figure 3). Visibility fan-out (VFO) is calculated by summing all the dependencies along each row of the matrix, including the diagonal. For example, file C has a VFO of 3, which means that it depends on 75% of the files in the software either directly or indirectly. Visibility fan-in (VFI) is calculated similarly, instead by summing down the columns of the visibility matrix. Continuing the example, file C is seen by both itself and file D.

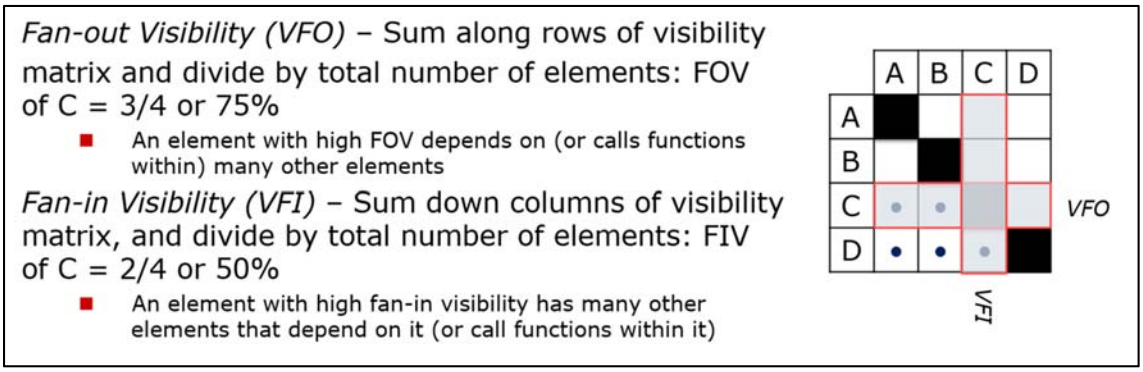

Figure 4. Calculations for Fan-Out Visibility and Fan-In Visibility

With visibility scores calculated, we now organize each file into one of four types of files (see Figure 5). This step is critical because previous work suggests files with high VFI and high VFO are statistically significant indicators of hardness-to-kill (MacCormack et al., 2007). However, high VFO by itself was not uniformly significant across all samples in

previous research, suggesting that high VFI is more dominant in explaining survival. Intuitively this makes sense; files with a high VFI score imply they are relied upon extensively by other files in the software. Substituting a file which is relied upon extensively by other files is difficult, whereas substituting a file which relies upon others (i.e., high VFO) is relatively easier. Consequently, we conclude the two types of components which are both more survivable and least substitutable fall into the "shared" and "core" classes (highlighted in red on Figure 5).

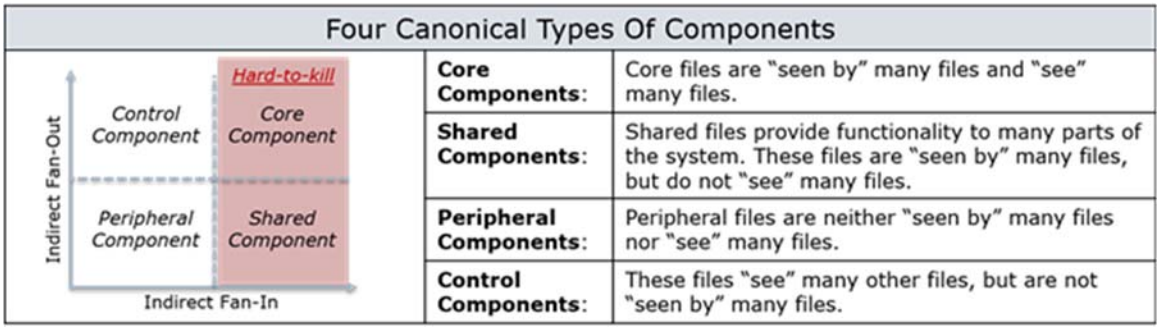

Figure 5. Four Canonical Types of Files
(adapted from Lagerström et al., 2013)

Case Study

To illustrate the utility of this methodology, we will examine a piece of DoD developed software and gain an understanding of which files have high switching costs and could result in intellectual property lock-in. Specifically, we will examine a flight simulator software currently under sustainment at Air Force Materiel Command. The end goal of this case study is to show how the method above can be utilized to identify a list of files for which the data rights should be secured to ensure future sustained competition.

This particular piece of software is comprised of 6,362 files primarily written in C++ and Java. Using the methodology described above, calls were extracted, visibility metrics calculated, and each file was organized into one of the four groups in Figure 5. The results are depicted in DSM at Figure 6. Recall from Figure 5 that the most important groups to determine substitutability and hardness-to-kill were the "shared" and "core" groups. These two groups are organized in the upper left corner of Figure 6 and are labeled accordingly. The files that fall into either shared or core comprise approximately 18% software, as a percentage of total files.

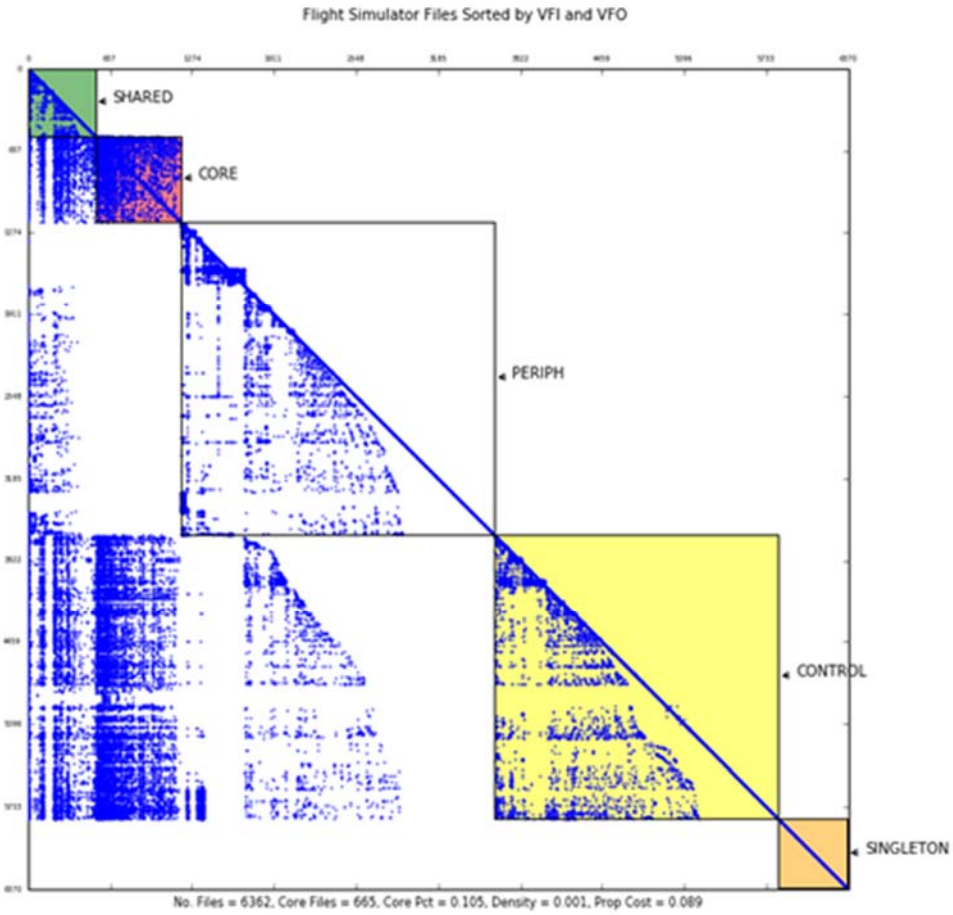

Figure 6. Flight Simulator Files Sorted by Visibility Fan-In and Visibility Fan-Out

We argue that this visual output and categorization of files should assist program managers in determining which data rights to purchase. Without this method the program manager would have had to decide which data rights in the 6,362 files were instrumental for future competition. Further exasperating the problem, there is a low likelihood that the program manager has any formal training in computer science or software development. The attractiveness of our methodology is that it allows for the prioritization of data rights without any understanding of the actual lines of code in each file. The program manager does not need to understand the function calls in any given file or even the purpose of each; he or she must only understand that one file calls another. From this we can identify the files which are difficult to separate from the software at large and are likely to survive in the software throughout multiple versions. In acquiring the rights to just this small percentage of files, we argue that it increases the likelihood of future sustained competition because the DoD has rights to the subset of files which are hardest to operate the software without.

Future Work/Conclusion

We have shown that there are no clear trends in the levels of competition in the DoD, as measured by ratios of J&As to contract awards, as a result of BBP. However, this is not to say that BBP is ineffectual, but that methodologies are still needed to implement the guidance outlined in BBP. To that end, we proposed a methodology to identify salient data rights in computer software, thus providing a means for program managers to understand which data rights are most important to ensure future sustained competition.

That being said, there are limitations to our proposed method. First, we make no attempt to account for the effects of file specific licenses on the prioritization of data rights. In the files identified in the flight simulator example, there could be open source files which carry varying license types[11] (e.g., General Public License, Lesser General Public License, Creative Commons, BSD, MIT, etc.). The presence of one or more of these licenses in the software could change which files the government is entitled data rights. Further work is needed to combine the license information at the file level into the methodology discussed herein. However, with more research we argue this obstacle is solvable.

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[11] The Free Software Foundation (FSF) lists 125 different open source copyright licenses. However, only 93 of the 125 are considered "free software" by the FSF definition, which is roughly "the users have the freedom to run, copy, distribute, study, change and improve the software" (Free Software Foundation, 2015). However, the standards of what qualifies as "free software" or open source software differ between organizations.

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