# What is Middleware Made Of?

## Exploring abstractions, concepts, and class names in modern middleware

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## ABSTRACT

Developing appropriate abstractions for distributed programming is one of the core aims of middleware research. Yet, analysing the impact, diffusion, and success of these abstractions in concrete middleware code is difficult and time consuming. In this paper we propose to use the constituting words found in program identifiers to explore the concepts used in popular middleware platforms. We study and compare four industrial middleware products (JBoss, Hadoop, Axi2, and ActiveMQ), and show the existence of a substantial core of shared concepts that we think capture some of the key tenets of modern middleware engineering.

## Categories and Subject Descriptors

C.2.4 [**Distributed Systems**]; I.2.7 [**Natural Language Processing**]: [Text analysis]

## Keywords

middleware, abstractions, identifiers

## 1. INTRODUCTION & MOTIVATION

One of the aims of middleware research is to find programming abstractions that make it easier to construct rich and complex distributed systems. Evaluating the success of these abstractions is however a complex and multi-faceted task. What are good middleware abstractions? Have abstractions proposed in the past worked? What has been their concrete impact on middleware products used in the field? Many researchers can provide intuitive answers to these questions, but we generally lack clear approaches to answer them in principled, systematic and reproducible ways.

Although questions on the impact of middleware abstractions are difficult to answer, they are critical to the field of middleware research: We need to know whether and how middleware abstractions are successful to inform and motivate future research, identify potential research gaps, and train future generations of researchers and practitioners. The need for principled approaches to evaluate the impact of middleware abstractions has led to early experimental works in this direction based on historical analysis [6], corpus linguistics [11], and cognitive analysis [9].

Although these methods have each been able to provide unique insights into middleware design and research, they are typically time-consuming and costly. They thus make it difficult to rapidly compare and contrast a broad range of different middleware systems. In this paper, we therefore propose a different strategy based on the analysis of *program identifiers*. Our hypothesis is that the concerns, mechanisms, and technologies used in a piece of middleware are (in part) reflected in the names given to its constituting elements (packages, classes, methods). To illustrate the importance of identifiers for developers, one just needs to imagine a reasonably complex piece of middleware (or API) in which identifiers have been obfuscated: for most practical development purposes, an unintelligible mess.

Identifiers are however often highly specific (e.g. CMPClusteredInMemoryPersistenceManager) and difficult to generalise from. We therefore follow a growing trend in experimental software engineering [5, 4, 7, 8] and focus instead of the constituting words of identifiers. These words usually denote the *concepts* used by developers to design and organise of a piece of middleware. Although the exact meaning of such words may vary between products (Hadoop's factories may not be exactly the same as those of JBoss), they are often generic enough to allow comparisons across multiple middleware source bases.

In this paper, we consider four popular open-source middleware products programmed in Java (JBoss, Hadoop, Axis2 and ActiveMQ) and conduct an explorative study of the concepts contained in their class and interface names. We investigate in particular to which extent these projects tend to share concepts, and what relationships can be found between these concepts. Finally we propose a rapid analysis of the Hadoop project based on our findings.

## 2. METHODOLOGY

In this preliminary work we focus solely on the names of public classes and interfaces, but the same approach would be applicable to other languages and program elements. For brevity's sake, we will often use 'class' in the rest of the paper to mean both public classes and interfaces.

### 2.1 Concept extraction

The first step consists in extracting the elements of a compound class name. We rely here on a set of simple regular expressions capturing the camel case commonly used in Java


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projects. To handle specific terms such as *J2EE*—which would be wrongly parsed as *J*, *2*, *EE*—we also use a greedy approach [3] based on a small ad hoc dictionary of problematic terms. For each class name $c$ we obtain a sequence of words which we note $\mathsf{concepts}(c)$, e.g. $\mathsf{concepts}(c) = [CMP, Clustered, In, Memory, Persistence, Manager]$. We consider each word refers to a concept, and use the two terms (*word* and *concept*) interchangeably.

## 2.2 Metrics

In order to rank and compare the concepts extracted from a corpus of class names $\mathcal{C}$ we use two metrics. The first one simply counts how many class names contain a concept $w$:

$$\mathsf{class\_count}(w) = |\{c \in \mathcal{C} : w \in \mathsf{concepts}(c)\}|$$

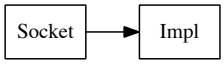
Our second metrics refines the first by taking into account the size of each class' code, thus giving more weight to concepts appearing in larger classes:

$$\mathsf{locs\_count}(w) = \sum_{c' \in \{c \in \mathcal{C} : w \in \mathsf{concepts}(c)\}} \mathsf{locs\_size}(c')$$

## 2.3 Inter-concept analysis

To analyse how concepts relate to each other, we use two tools: *n-grams*, a tool commonly used in computer linguistics, and *conceptual graphs*, which we describe just below. n-grams [2] capture collocations, i.e. words repeatedly appearing together. An n-gram model essentially counts how often particular tuples of words (pairs, triplets, etc.) appear together. Frequent tuples often represent a specific meaning, beyond the meaning of their individual constituents. For instance the 3-gram *blue sky research* appears much more often in English texts than *brown sky research* because it denotes a well delineated meaning, which the other does not.

To visualise links between concepts, we use a graph representation that builds on the sequence of concepts found in each class name. A sequence $s$, e.g. $s = [Socket, Impl]$, is a simple graph $G(s)$ with two nodes and one directed edge:




$$G(s) = \Big(V(s) = \{Socket, Impl\}, E(s) = \big\{(Socket, Impl)\big\}\Big)$$

The *conceptual graph* of a corpus of class names $\mathcal{C}$ is simply defined of the union of the graphs representing its concept sequences:

$$G(\mathcal{C}) = \Big(\bigcup_{c \in \mathcal{C}} E\big(\mathsf{concepts}(c)\big), \bigcup_{c \in \mathcal{C}} V\big(\mathsf{concepts}(c)\big)\Big)$$

# 3. RESULTS

In this study we consider four open-source middleware projects that are representative of the wide-range of available Java-based middleware. These are the J2EE application server *JBoss* from RedHat, and three projects from the Apache Foundation: the distributed map-reduce engine *Hadoop*, the Web Service engine *Axis2/Java*, and the message-oriented middleware *ActiveMQ*. These projects all support the development of distributed systems, but differ in the services and technologies they provide. They are used in production, and generally follow good and clearly documented development practices. They remain diverse, however, and although three (Hadoop, Axis2, and ActiveMQ) belong to the Apache Foundation, they are managed and developed by distinct teams, in independent projects, under their own architecture and coding conventions.

Each project is substantial, containing between 247k and 345k lines of Java code (LoCs), and between 1514 and 2990 public Java classes and interfaces (ignoring comments, test and sample code, Table 1).

**Table 1: The four middleware projects considered**

| *middleware* | *LoCs* | *# classes* |
|---|---|---|
| JBoss AS (6.0.0) | 345,063 | 2,290 |
| Hadoop (1.0.3) | 255,563 | 1,327 |
| Axis2 (1.6.2) | 302,315 | 1,514 |
| ActiveMQ (5.6.0) | 247,801 | 1,873 |
| **Total** | **1,150,742** | **7,004** |

## 3.1 Vocabulary size and distribution

Table 2 shows the number of class concepts, concepts for short, found in each project. These numbers make clear the benefit of concepts over class names to analyse projects: The projects use between 1.71 (Hadoop) and 3.21 (ActiveMQ) fewer concepts than they do class names, with the ratio getting close to 4 (1,861 concepts for 7,004 public classes) when considering all projects together (Tables 1 and 2).

**Table 2: Size of concept vocabulary per project**

| *middleware* | *# concepts* | *per class (avg)* | *min* | *max* |
|---|---|---|---|---|
| JBoss | 949 | 3.31 | 1 | 8 |
| Hadoop | 776 | 2.65 | 1 | 8 |
| Axis2 | 646 | 2.79 | 1 | 7 |
| ActiveMQ | 583 | 2.96 | 1 | 7 |
| **All projects** | **1861** | **2.98** | **1** | **8** |

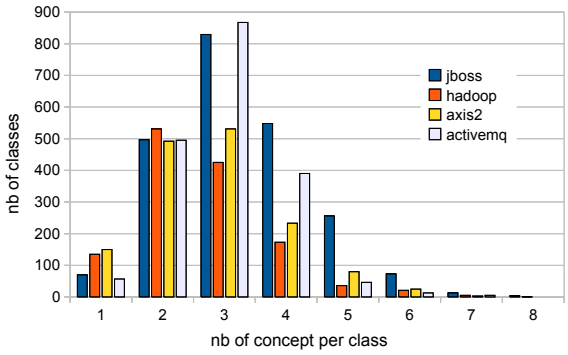



**Figure 1: Number of concepts per class name**

Concepts are rarely used alone. They are instead the basic building blocks from which class names are formed (Figure 1). In all projects, the vast majority of classes (94.12%) use more than two concepts in their name, with more than half (65.35%) containing three concepts or more. This is again reflected in an averaged number of concepts per class of 2.98 (Table 2). This general trend hides however important differences between projects: Hadoop for instance stands out as a project with the lowest number of classes (1,327), but the second highest number of concepts (776). Although it has comparatively more concepts and fewer classes, Hadoop also has counter-intuitively the lowest

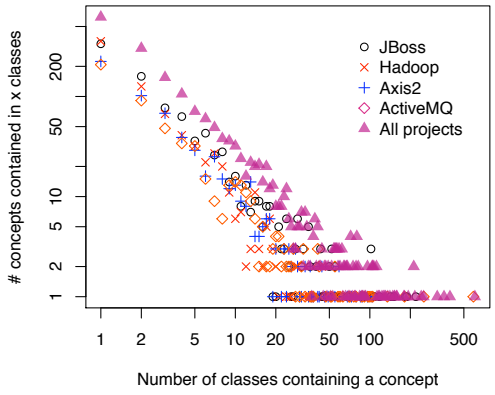



**Figure 2: Concept frequencies among class names**

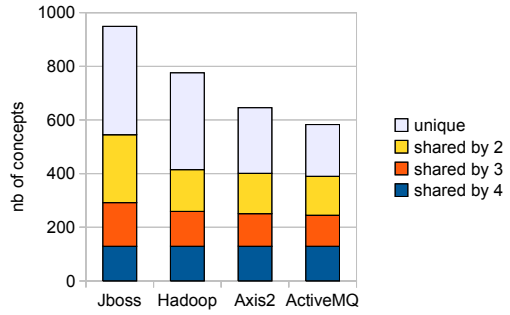



**Figure 3: Concept corpus size and sharing**

average number of concepts per class (2.65, Table 2), and a minority of classes (49.81%) with three concepts or more.

In terms of relative frequencies, Figure 2 shows the frequency distribution of concepts in each individual projects, and globally. I.e. Figure 2 shows how many concepts (y-axis) appear in a particular number of classes (x-axis), on a log-log scale. For instance, the top-left black circle indicates that JBoss contains 336 concepts (35.4%) which appear in exactly one JBoss class. Similarly, the top-left dark pink triangle means that across all projects 621 concepts (33.4%) appear in exactly one class. Figure 2 clearly shows how all distributions tend to follow power laws, a typical feature of both natural languages, and human created networks such as folksonomies and social networks.

These observations suggest that the concepts that make up class names in middleware projects play a similar role to that of words in natural text. As such, they represent a promising entry point to study the abstractions used in modern middleware. In the following we focus more particularly on concepts shared between projects and ask the following questions: Do different middleware projects tend to share concepts? If yes, which ones? To which extent? What can shared concepts tell us about individual projects and the state of current middleware practices?

## 3.2 Concept sharing between projects

Sharing comes in different shades. At one extreme, concepts that are highly specific to one project (such as 'HA' for High-Availability in JBoss) are unique to this project and not shared. At the other extreme, highly generic concepts (e.g. 'Data') will tend to appear in all projects, with common but less generic concepts falling in-between. To investigate these different degrees of sharing, Figure 3 shows how many concepts are shared in each project, depending on how many other projects share a particular concept. The first observation is that all projects share a high proportion of their concepts (between 53.5% for Hadoop and 66.9% for ActiveMQ) with at least one other project. Size plays a role in the amount of common concepts: The smallest project (ActiveMQ, 186kloc) shares more with other projects (66.9% of its concepts) than the largest project (JBoss, 332kloc, 57.4% of shared concepts). Size is not, however, the only factor, as the numbers for Hadoop illustrate. Although Hadoop has a similar number of lines as Axis, and fewer classes, it also shows lower levels of concept sharing (53.5% for Hadoop, against 62.1% for Axis2).

What is the relative importance of these shared concepts? Although they represent a large proportion of the overall concept vocabulary, shared concepts might only appear in a minority of class names, with most classes using concepts unique to the project at hand. To answer this question, Table 3 looks at the number of classes that contain at least one shared concept in their name.

**Table 3: Class names containing shared concepts**

| *middleware* | *# shared concepts* | *# classes* | *% classes* |
|---|---|---|---|
| JBoss | 545 | 2,245 | 98.0% |
| Hadoop | 415 | 1,211 | 91.3% |
| Axis2 | 401 | 1,431 | 94.5% |
| ActiveMQ | 390 | 1,860 | 99.3% |

Table 3 shows that shared concepts appear in almost all classes in all projects. As a corollary, very few classes only contain project-specific concepts: less than 1% in ActiveMQ, less than 2% in JBoss, less than 5% in Axis2. Although showing the same trend, Hadoop stands out again with 10% of classes containing no shared concept.

If we now turn to the percentage of classes that only contain shared concepts, the numbers are similarly high, with a majority of classes only containing shared concepts in JBoss (52.4%), Axis2 (56.2%) and ActiveMQ (58.4%), and almost half of classes doing the same in Hadoop (47%).

## 3.3 Sharing and semantic

The numbers we have just discussed demonstrate the existence of a *substantial shared vocabulary* between the four middleware projects we have selected. This shared vocabulary must be understood by anyone wishing to use and contribute to these projects. More generally it also exposes in a tangible way the existence of a shared foundation to distributed programming platforms.

What is this shared foundation made of? To shed light on this question, we now focus on those concepts shared by all four projects, meant to represent the most generic part of our concept corpus. Table 4 lists the first 15 most common concepts shared by all projects, sorted according to the total number of lines of code (locs) they cover (first and second columns). For completeness, we also show the number of classes each concept appears in (third and fourth columns), and the percentages of locs they cover in each project (second half of the table). The 'rank' column indicates the overall rank of each concept (sorted by locs) among

**Table 4: The top 15 concepts (in locs) shared by all projects**

| *Concept* | *locs* | % | *classes* | % | *rank* | *JBoss* | *Hadoop* | *Axis2* | *ActiveMQ* | *CV* |
|---|---|---|---|---|---|---|---|---|---|---|
| **Impl** | 52,205 | 4.54% | 241 | 3.44% | 2 | 4.29% | 0.63% | 10.25% | 1.93% | 0.86 |
| Service | 50,948 | 4.43% | 212 | 3.03% | 3 | 5.30% | 0.26% | 9.30% | 1.57% | 0.86 |
| *Data* | 50,667 | 4.40% | 317 | 4.53% | 4 | 7.70% | 2.51% | 1.60% | 5.19% | 0.56 |
| Message | 50,013 | 4.35% | 356 | 5.08% | 5 | 1.09% | 0.02% | 4.25% | 13.45% | 1.12 |
| **Factory** | 42,788 | 3.72% | 394 | 5.63% | 6 | 7.34% | 0.85% | 2.22% | 3.48% | 0.70 |
| *File* | 41,795 | 3.63% | 179 | 2.56% | 7 | 0.64% | 11.86% | 1.33% | 2.14% | 1.15 |
| **Manager** | 37,238 | 3.24% | 153 | 2.18% | 8 | 7.46% | 2.65% | 0.91% | 0.80% | 0.92 |
| Connection | 36,856 | 3.20% | 216 | 3.08% | 9 | 5.52% | 0.05% | 0.43% | 6.62% | 0.93 |
| *Context* | 29,051 | 2.52% | 148 | 2.11% | 12 | 2.58% | 0.85% | 4.74% | 1.48% | 0.61 |
| *Stream* | 28,165 | 2.45% | 123 | 1.76% | 13 | 0.63% | 3.35% | 2.39% | 4.11% | 0.50 |
| **Abstract** | 24,690 | 2.15% | 129 | 1.84% | 16 | 4.45% | 0.71% | 1.34% | 1.40% | 0.74 |
| *Meta* | 23,226 | 2.02% | 159 | 2.27% | 18 | 6.30% | 0.05% | 0.40% | 0.05% | 1.56 |
| *Info* | 23,111 | 2.01% | 193 | 2.76% | 19 | 0.87% | 0.63% | 0.57% | 6.76% | 1.19 |
| **Command** | 21,640 | 1.88% | 212 | 3.03% | 20 | 2.76% | 0.18% | 0.48% | 4.12% | 0.87 |
| **Utils** | 21,003 | 1.83% | 77 | 1.10% | 23 | 0.16% | 1.61% | 5.34% | 0.06% | 1.19 |

all other concepts, whether shared or not. Finally the last column ('CV') reports the *coefficient of variation* of the locs percentages across the projects. This coefficient measures the *dispersion* of each concept: low numbers indicate concepts evenly distributed across projects, while high numbers highlight concepts mainly concentrated in a few projects.

**Ranking and dispersion.** The first observation is that the top concepts in terms of locs are shared: The concepts shared by all projects make up 8 of the top-10 concepts ($6^{th}$ column, 'rank'). The two top-10 concepts not appearing in the table are *Marshaller* (#1) and *Job* (#10) which are present in 3 projects, and so remain heavily shared.

In spite of this observation, top shared concepts are not equally distributed among projects (last column, *CV*), but instead tend to appear heavily in one or two projects, while only sporadically in others. Even the two concepts most evenly distributed in the table (*Data*, #4, and *Stream*, #13) have high CV values (0.56 and 0.50) when compared to the concepts with the lowest CV overall: *Thread* (0.15, #378), *Exception* (0.16, #115), and *Xml* (0.22, #292). This means that in spite of an important foundation of shared concepts, each project retains a strong identity that clearly differentiates it from other projects. This also opens interesting avenues of comparative studies: Why are for instance *Factories* much less common in Hadoop than in other projects? Does this represent an obvious different design? Or simply different naming conventions? Could this suggest opportunities for evolution or refactorisation?

**Semantic.** Although the concepts captured in Table 4 seem to cover a large range of concerns, they can roughly be classified in three categories (indicated in italics, normal font, and bold, respectively). Some concepts denote *generic* computer science and system-level abstractions (*Data*, *File*, *Context*, *Stream*, *Meta*, *Info*). Other concepts are more *domain-specific* (*Service*, *Message*, *Connection*), and cover abstractions typically associated with distributed systems. A longer table would show more of these, with *Client* and *Server* appearing for instance in all projects at rank #30 and #35. Finally, the remaining concepts capture *design patterns* (even if some might describe utility classes as an anti-pattern), i.e. particular ways to organise code and behaviour in object-oriented software. Here again, differences are apparent between projects, with JBoss a clear heavy user of templates, and Hadoop much less so.

Comparing the shared concepts of Table 4 with concepts that are unique to specific projects (Table 5 for JBoss and Hadoop) highlights the transversal nature of pattern concepts. Although some generic abstractions can still be found (*Verifier*, *Domain*, *FS* for File System) in the top-10 concepts unique to JBoss and Hadoop, most of them refer to specific technologies (e.g. CMP and CMR are both taken from the EBJ standard, Thrift is a cross-platform RPC product), with no mention of any design template.

**Table 5: Unique concepts in JBoss and Hadoop**

(a) **JBoss**

| *Concept* | *rank* | *%locs* |
|---|---|---|
| JBoss | 24 | 5.83% |
| HA | 95 | 2.25% |
| *Verifier* | 99 | 2.21% |
| Clustered | 129 | 1.78% |
| Statement | 137 | 1.64% |
| CMP | 157 | 1.39% |
| QL | 170 | 1.26% |
| *Domain* | 179 | 1.20% |
| CMR | 180 | 1.19% |
| *JDK* | 206 | 1.05% |

(b) **Hadoop**

| *Concept* | *rank* | *%locs* |
|---|---|---|
| *FS* | 46 | 5.21% |
| Hadoop | 57 | 4.69% |
| Thrift | 111 | 2.68% |
| DFS | 118 | 2.55% |
| *Namesystem* | 141 | 2.14% |
| *History* | 171 | 1.68% |
| Reduce | 176 | 1.65% |
| *Writable* | 214 | 1.36% |
| Zip | 263 | 1.07% |
| CB | 262 | 1.07% |

## 3.4 Inter-concept relationships

Although we have so far analysed the weight, rank, and semantics of individual concepts, most concepts are used in combination with others. Only 3.71% of all concepts (69 out of 1861) are used in complete isolation, never appearing with any other concept in class names. Many of these isolated concepts are concentrated in Hadoop (5.8%) and Axis2 (5.11%), with JBoss and ActiveMQ showing much lower levels (1.79% and 1.54% respectively).

**Table 6: n-grams shared by all projects**

| ngram | global # | JBoss | Hadoop | Axis2 | ActiveMQ |
|---|---|---|---|---|---|
| *Meta Data* | 152 | 149 | 1 | 1 | 1 |
| *Input Stream* | 35 | 4 | 16 | 6 | 9 |
| *Output Stream* | 25 | 3 | 12 | 3 | 7 |
| Context **Factory** | 15 | 7 | 1 | 5 | 2 |

We therefore now focus on the relationships between concepts, using n-grams (Section 2) to capture their tendency

**Table 7: n-grams shared by 3 projects**

| ngram | global # | JBoss | Hadoop | Axis2 | ActiveMQ |
|---|---|---|---|---|---|
| Connection **Factory** | 55 | 37 | – | 1 | 17 |
| *Data Source* | 44 | 24 | – | 19 | 1 |
| **Factory Impl** | 38 | 11 | – | 26 | 1 |
| Proxy **Factory** | 26 | 23 | – | 2 | 1 |
| *File System* | 25 | – | 23 | 1 | 1 |
| *Class Loader* | 20 | 11 | – | 8 | 1 |
| Socket **Factory** | 16 | 13 | 2 | 1 | – |
| *Byte Array* | 14 | 1 | 5 | – | 8 |
| Connection **Manager** | 14 | 11 | – | 2 | 1 |
| Reference **Factory** | 6 | 1 | – | 4 | 1 |
| Object Input | 6 | 2 | – | 3 | 1 |
| **Manager Impl** | 5 | 2 | – | 2 | 1 |
| Application Context | 5 | 1 | – | 3 | 1 |
| *Object Input Stream* | 5 | 2 | – | 2 | 1 |
| Callback **Handler** | 5 | 2 | – | 1 | 2 |
| Http Server | 5 | 2 | 2 | 1 | – |
| Exception **Handler** | 4 | 1 | 1 | – | 2 |
| *Xml File* | 4 | 2 | – | 1 | 1 |
| *Round Robin* | 4 | 2 | 1 | – | 1 |
| Bounded Range | 4 | 2 | 1 | – | 1 |
| **Handler Factory** | 3 | 1 | 1 | 1 | – |
| MBean Info | 3 | 1 | 1 | – | 1 |
| Java Generator | 3 | – | 1 | 1 | 1 |
| *File Reader* | 3 | – | 1 | 1 | 1 |

to appear together. When applied to our corpus of class names, we found a total of 3757 n-grams appearing more than once, with a majority (61.54%) of bi-grams. In terms of sharing, n-grams show a different behaviour than individual concepts. First, only a small minority (8.25%) of n-grams are shared. Second, the most frequent n-grams tend to be specific to one or two projects. For instance, out of the 20 most common n-grams in terms of frequencies, a majority (12) are not shared, while only 2 (*Meta Data*, #1, and *Input Stream*, #14) can be found in all projects.

These differences between individual concepts (whose most frequent representatives tend to be shared) and n-grams (showing the opposite trend) highlights the building block nature of concepts. Although the most common concepts tend to appear in most projects, the ways in which they are combined are specific to each project. Our conjecture is that these combinations capture the identity of each project along with its main design philosophy.

For space reasons, we focus in the following on shared n-grams, with the n-grams shared by all projects listed in Table 6, and those shared by all but one in Table 7. Most of these generic n-grams fall in two main categories: 13 n-grams (shown in italic) simply capture generic multi-words notions, such as *Input Stream*, or *File System*. Another set of 10 n-grams (shown with some of their words in bold) represent application of design templates (*Factory*, *Manager*, *Handler*), some of which were identified in Table 4. This shows for instance that factories, although primarily used in JBoss, are used in other projects to handle connections, sockets, and context (the latter being essentially used for JNDI naming operations, and invocation handling). These "template" n-grams also highlight how design templates are applied to elements of the domain (sockets, connections, naming contexts) to provide desirable properties (in the case of factories, configurability through dependency injection).

## 3.5 Visualisation: Hadoop

Finally, we briefly illustrate how concepts can help analyse a particular piece of middleware, Hadoop in our case. An extract of Hadoop's conceptual graph (cf. Section 2) showing Hadoop's most important concepts is shown in Figure 4. The graph provides a good intuition of the key elements of Hadoop: Hadoop is about a file system (HFS), map and reduce tasks, and jobs. These three different areas have little overlap: FS concepts, task concepts, and job concepts are only connected through concepts denoting cross-cutting concerns (logging, auditing).

Strikingly, most of Hadoop's top concepts in terms of locs are shared (red and orange colours), but none of them are design templates. This second point probably explains some of the anomalies we have noted about Hadoop in terms of class name length and sharing: Hadoop class names are mainly focused on domain concepts, with issues of code organisation and configurability left to other means (reflection, annotations, Spring and Guice for instance).

# 4. RELATED WORK

The importance of identifiers and concepts in software has long been noted [10]. This key role has motivated a growing body of experimental work on identifiers in the software engineering community, in particular in terms of program comprehension, software maintenance and reverse-engineering. None of these works explicitly target middleware, however. Instead they tend to seek general rules and methods , rather than gain domain-specific insights as we have tried in this paper. We review some of these works below.

Some works have focused on the concepts and topics underlying a particular piece of software. For instance, in [1], Alan Blackwell investigated the metaphors used in the javadoc documentation of the standard Java libraries. Blackwell observed that Java objects tend to be presented as members of a society with rights and obligations (contracts). In another work, Kuhn, Ducasse and Tudor [8] applied Latent Semantic Indexing (LSI) to the vocabulary found in software (both in comments and in identifier names) to extract and represent the key topics present in a source code.

Other works have more systematically analysed the nature of the parts making up identifier names. Working across 29 Java projects (including JBoss and Axis), Høst and Østvold [7] investigated how the initial part of method names (usually a verb such a 'get', or 'load') is linked to semantic features of the code (i.e. "the method body contains a loop"). Using this approach, they showed they could distinguish between well-defined concepts, whose meaning vary little across projects, from more variable ones.

In [4], Butler et al. found a positive relationship between the quality of identifiers in Java code (as captured by best practices for naming) and the quality of the code the identifiers refer to (as captured by existing metrics for code quality and complexity). In an other work, Butler et al. [5], performed a cross-comparison of the part of speech structure of class names (e.g. "adjective-noun") and types of inheritance in Java (interfaces vs. classes), and found that the structure of 90% of Java class names could be captured using four grammatical rules, while some types of inheritance were more strongly correlated to some rules than others.

# 5. CONCLUSION AND OUTLOOK

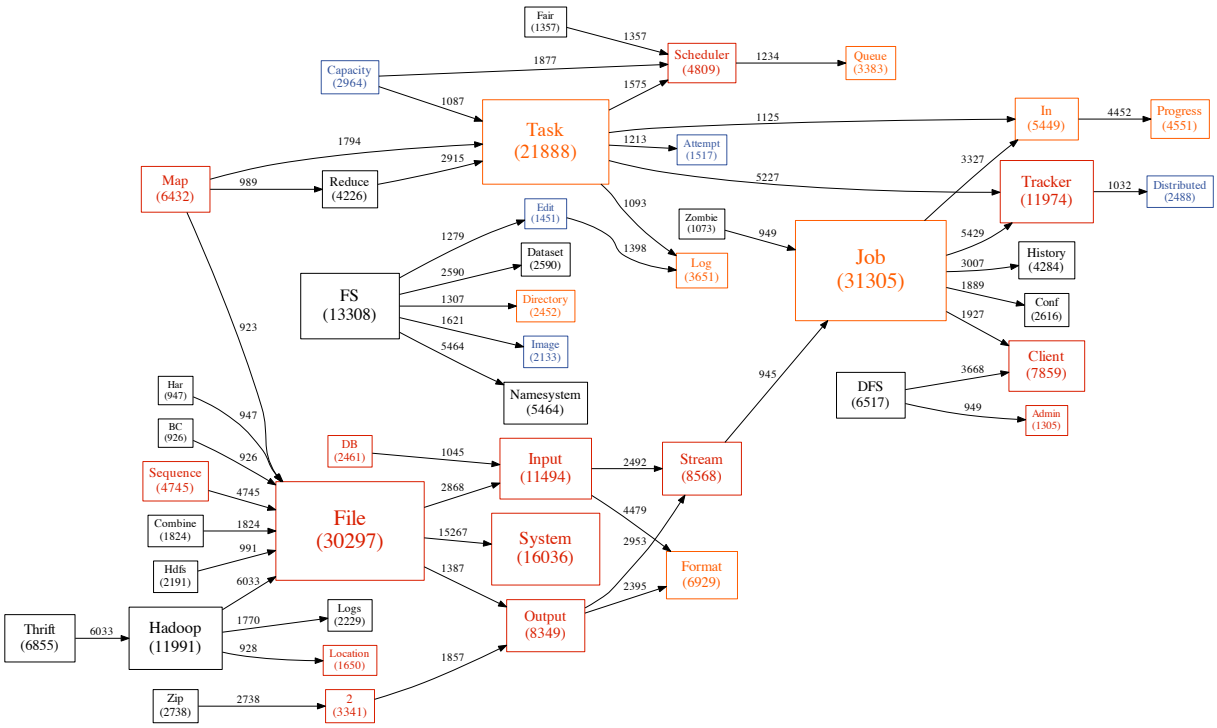



**Figure 4: Main concepts in Hadoop 1.0.3. Node labels show the locs count of each concept. Edge labels show the number of locs involved in a connection. Black concepts are unique to Hadoop; blue concepts are shared with one other project; orange ones with two others; and red ones with all others.**

In this paper we have explored how the words contained in class name identifiers of middleware products could help capture the key concepts used in these projects. By looking at four popular Java-based middleware products we have found an important vocabulary of shared concepts, which should prove useful to suggest research avenues and inform training on middleware technologies. Interestingly, a large proportion of concepts are not about distribution, but about code organisation through patterns (e.g. dependency injection). In spite of this sharing, we have also found that different projects use concepts differently. These differences reflects the different aims of each project. They probably also reflect different design philosophies, which opens up the prospect of interesting comparative studies (Is Hadoop less adaptable than JBoss?) and potential paths for cross-pollination.

We have not looked specifically at what each concept entails, a crucial point we would like to consider in future works. Does the same concept represent the same thing across projects? Can we capture some of a concept's meaning by looking at the identifiers of programmatic elements attached to it (e.g. using methods names to cast light on class names)? Another interesting avenue would be to try to use concepts to build a typology of middleware functions across several middleware products by leveraging clustering techniques based on concept usage and similarity.

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