A Domain-independent Rule-based Framework for Event Extraction

Marco A. Valenzuela-Escárcega  Gus Hahn-Powell  Thomas Hicks  Mihai Surdeanu
University of Arizona, Tucson, AZ, USA
{marcov,hahnpowell,msurdeanu,hickst}@email.arizona.edu

Abstract
We describe the design, development, and API of ODIN (Open Domain INformer), a domain-independent, rule-based event extraction (EE) framework. The proposed EE approach is: simple (most events are captured with simple lexico-syntactic patterns), powerful (the language can capture complex constructs, such as events taking other events as arguments, and regular expressions over syntactic graphs), robust (to recover from syntactic parsing errors, syntactic patterns can be freely mixed with surface, token-based patterns), and fast (the runtime environment processes 110 sentences/second in a real-world domain with a grammar of over 200 rules). We used this framework to develop a grammar for the biochemical domain, which approached human performance. Our EE framework is accompanied by a web-based user interface for the rapid development of event grammars and visualization of matches. The ODIN framework and the domain-specific grammars are available as open-source code.

1 Introduction
Rule-based information extraction (IE) has long enjoyed wide adoption throughout industry, though it has remained largely ignored in academia, in favor of machine learning (ML) methods (Chiticariu et al., 2013). However, rule-based systems have several advantages over pure ML systems, including: (a) the rules are interpretable and thus suitable for rapid development and domain transfer; and (b) humans and machines can contribute to the same model. Why then have such systems failed to hold the attention of the academic community? One argument raised by Chiticariu et al. is that, despite notable efforts (Appelt and Onyskheyvych, 1998; Levy and Andrew, 2006; Hunter et al., 2008; Cunningham et al., 2011; Chang and Manning, 2014), there is not a standard language for this task, or a “standard way to express rules”, which raises the entry cost for new rule-based systems.
Here we aim to address this issue with a novel event extraction (EE) language and framework called ODIN (Open Domain INformer). We follow the simplicity principles promoted by other natural language processing toolkits, such as Stanford’s CoreNLP, which aim to “avoid over-design”, “do one thing well”, and have a user “up and running in ten minutes or less” (Manning et al., 2014). In particular, our approach is:

Simple: Taking advantage of a syntactic dependency representation (de Marneffe and Manning, 2008), our EE language has a simple, declarative syntax (see Examples 1 & 2) for \( n \)-ary events, which captures single or multi-word event predicates (\textit{trigger}) with lexical and morphological constraints, and event arguments (e.g., \textit{theme}) with (generally) simple syntactic patterns and semantic constraints.

Powerful: Despite its simplicity, our EE framework can capture complex constructs when necessary, such as: (a) recursive events\(^2\), (b) complex regular expressions over syntactic patterns for event arguments. Inspired by Stanford’s Semgrex\(^3\), we have extended a standard regular expression language to describe patterns over directed graphs\(^4\), e.g., we introduce new \(<\) and \(>\) operators to specify the direction of edge traversal in the dependency graph. Finally, we allow for (c) optional arguments\(^5\) and multiple arguments with the same name.

Robust: To recover from unavoidable syntactic errors, SD patterns (such as the ones in Examples 1 and 2) can be freely mixed with surface, token-based patterns, using a language inspired by the Allen Insti-
tute of Artificial Intelligence’s Tagger⁶. These patterns match against information extracted in our text processing pipeline⁷, namely a token’s part of speech, lemmatized form, named entity label, and the immediate incoming and outgoing edges in the SD graph. Example 3 shows an equivalent rule to the one in Example 1 using surface patterns (i.e., a pattern that is independent of a token sequence’s underlying syntactic structure).

**Fast:** Our EE runtime is fast because our rules use event trigger phrases, captured with shallow lexico-morphological patterns, as starting points. Only when event triggers are detected is the matching of more complex syntactic patterns for arguments attempted. This guarantees quick executions. For example, in the biochemical domain (discussed in Section 2), our framework processes an average of 110 sentences/second⁸ with a grammar of 211 rules on a laptop with an i7 CPU and 16GB of RAM.

### 2 Building a Domain from Scratch

We next describe how to use the proposed framework to build an event extractor for the biochemical domain (Ohta et al., 2013) from scratch.

Rule-based systems have been shown to perform at the state-of-the-art for event extraction in the biology domain (Peng et al., 2014; Bui et al., 2013). The domain, however, is not without its challenges. For example, it is not uncommon for biochemical events to contain other events as arguments. Consider the example sentence in Figure 1. The sentence contains two events, one event referring to the biochemical process known as phosphorylation, and a recursive event describing a biochemical regulation that controls the mentioned phosphorylation. We will introduce a minimal set of rules that capture these two events. Here, we will assume the simple entities (denoted in bold in Figure 1) have already been detected through a named entity recognizer.⁹

When a rule matches, the extracted token spans for trigger and arguments, together with the corresponding event and argument labels (here the event label is Phosphorylation, and the argument labels are theme & cause) are dispatched to a labeling action. By default, these actions simply create an EventMention Scala object with the corresponding event label, and the extracted named arguments. Example 5 summarizes the EventMention class. Custom actions may be defined as Scala code, and be attached to specific rules. For example, a custom action may trigger coreference resolution when a rule matches a common noun, e.g., the protein, instead of the expected named entity.

The second rule, shown in Example 2, captures the recursive event in Figure 1. Importantly, this rule takes other events as arguments, e.g., the controlled argument must be an event mention, here generated by the rule in Example 1. To guarantee correct execution, the runtime repeatedly applies the given EE grammar on each sentence until no rule matches. For example, here the rule in Example 2 would not match in the first

**Figure 1:** An example sentence containing a recursive event.

```
- name: Phosphorylation_1
  priority: 2
  label: [Phosphorylation, Event]
  pattern:
    trigger = [lemma="phosphorylation"]
    theme:PhysicalEntity = prep_of
      (nn|conj|cc)*
    cause:PhysicalEntity? = prep_by
      (nn|conj|cc)*
```

**Example 1:** An example of a rule using syntactic structure. For the phosphorylation event, our selected event trigger (LINE 5) is a nominal predicate with the lemma phosphorylation. This trigger serves as the starting point for the syntactic patterns that extract event arguments. When searching for a theme to the Phosphorylation event, we begin at the specified trigger and look for an incoming dependent that is the object of the preposition of. The pattern fragment (nn|conj|cc)* targets entities that appear as modifiers in noun phrases (e.g., *of the cyclin-D1 protein*), or a series of arguments in a coordinated phrase. The entity mention associated with our theme must be a named entity with the label PhysicalEntity (LINE 7), a hyponym of several more specialized types identified in an earlier iteration. The cause argument is marked as optional (denoted by the ? symbol).

| Rule 1   | Pattern |
|----------|---------|
| Example 1| Line 1  |
| Example 2| Line 2  |

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⁶https://github.com/allenai/taggers
⁷https://github.com/sistanlp/processors
⁸after the initial text processing pipeline
⁹Though the discussion focuses on event extraction, our framework can also be applied to the task of entity recognition.
Example 2: An example of a rule designed to capture a recursive event. The rule detects a relevant verbal or adverbial trigger and expects its arguments to be in a SUBJECT ↔ DIRECT OBJECT relationship. The controlled argument must be the mention of another event.

Example 3: An alternative rule to Example 1 that uses a surface pattern. Surface patterns match event triggers and arguments over sequences of tokens and other mentions (e.g., the theme matches over an entire named entity of type PhysicalEntity). Event triggers (trigger) match the whole sequence of tokens encompassed in parentheses. Argument names preceded by the @ symbol, e.g., @theme, require the specification of an event type (denoted by :type). This pattern is shorthand for matching the span of an entire named entity with the specified type.

iteration because no event mentions have been created yet, but would match in the second iteration. This process can optionally be optimized with rule priorities (as shown in the figure). For example, the priorities assigned to Examples 1 and 2 enforce that the second rule is executed only in an iteration following the first rule. Utilizing rule priorities allows for a derivational construction of complex events or complete grammars from their components.

Once the grammar has been defined, the entire system can be run in less than 10 lines of code, as shown in Example 4. The output of this code is a collection of event mentions, i.e., instances of the EventMention class outlined in Example 5.

3 Visualization

We accompany the above EE system with an interactive web-based tool for event grammar development and results visualization. Figure 2 shows the input fields for the user interface. The UI accepts free text to match against, and can be configured to run either a predefined domain grammar or one provided on-the-fly through a text box, allowing for the rapid development and tuning of rules.
class EventMention {
    /** The ontological labels associated with */
    val label: Seq[String],
    /** The starting point of our pattern */
    val trigger: TextBoundMention,
    /** A mapping of argument names to the */
    val arguments: Map[String, Seq[Mention]],
    /** The name of the corresponding rule */
    val foundBy: String,
    /** The span of the Mention */
    val span: (tokenInterval : Interval)
}

Example 5: Example 4 produces a set of mentions. Here we focus on mentions of events (EventMention). This code block shows relevant fields in the EventMention class, which stores each event mention detected and assembled by the system. The arguments field captures the fact that the mapping from names to arguments is one-to-many (e.g., there may be multiple theme arguments). Interval stores a token span in the input text. TextBoundMention stores a simple mention, minimally a label and a token span.

More importantly, this evaluation offers a good platform to analyze the potential of the proposed rule-based framework, by estimating the ceiling performance of our EE system, when all addressable issues are fixed. We performed this analysis after the evaluation deadline, and we manually:

1. Removed the keys that do not encode direct biochemical reactions.
2. Corrected three rules, to better model one event and one entity type.
3. Fixed system bugs, including XML parsing errors, which caused some meta data to appear in text and be misinterpreted as biological entities, and a syntax error in one rule, which caused several false positives.

The results of this ceiling system are listed in the second row in Table 1. This analysis highlights an encouraging finding: the current rule framework is expressive: it can capture approximately 80% of the events in this complex domain. The remaining 20% require coreference resolution and complex syntactic patterns, which were not correctly captured by the parser.

5 Related Work

Despite the dominant focus on machine learning models for IE in the literature, previous work includes several notable rule-based efforts. For example, GATE (Cunningham et al., 2011), and the Common Pattern Specification Language (Appelt and Onyshkevych, 1998) introduce a rule-based framework for IE, implemented as a cascade of grammars defined using surface patterns. The ICE system offers an active-learning system that learns named entity and binary relation patterns built on top of syntactic dependencies (He and Grishman, 2011). Stanford’s Semgrex and Tregex (Levy and Andrew, 2006) model syntactic patterns,
while a separate tool from the same group, Tokens-Regex (Chang and Manning, 2014), defines surface patterns over token sequences. Chiticariu et al. (2011) demonstrated that a rule-based NER system can match or outperform results achieved with machine learning approaches, but also showed that rule-writing is a labor-intensive process even with a language specifically designed for the task.

In addition to the above domain-independent frameworks, multiple previous works focused on rule-based systems built around specific domains. For example, in bioinformatics, several dedicated rule-based systems obtained state-of-the-art performance in the extraction of protein-protein interactions (PPI) (Hunter et al., 2008; Huang et al., 2004).

Our work complements and extends the above efforts with a relatively simple EE platform that: (a) hybridizes syntactic dependency patterns with surface patterns, (b) offers support for the extraction of recursive events; (c) is coupled with a fast runtime environment; and (d) is easily customizable to new domains.

6 Conclusion

We have described a domain-independent, rule-based event extraction framework and rapid development environment that is simple, fast, powerful, and robust. It is our hope that this framework reduces the entry cost in the development of rule-based event extraction systems.

We demonstrated how to build a biomedical domain from scratch, including rule examples and simple Scala code sufficient to run the domain grammar over free text. We recently extended this grammar to participate in the DARPA Big Mechanism evaluation, in which our system achieved an F1 of 37%. By modeling the underlying syntactic representation of events, our grammar for this task used an average of only 11 rules per event; this indicates that the syntactic structures of events are largely generalizable to a small set of predicate frames and that domain grammars can be constructed with relatively low effort. Our post-hoc analysis demonstrated that the system’s true ceiling is 82%. This important result demonstrates that the proposed event extraction framework is expressive enough to capture most complex events annotated by domain experts.

Finally, to improve the user experience by aiding in the construction of event grammars, our framework is accompanied by a web-based interface for testing rules and visualizing matched events.

This whole effort is available as open-source code at: https://github.com/sistanlp/processors. See also: https://github.com/sistanlp/processors/wiki/ODIN-(Open-Domain-INformer), for ODIN documentation.

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