Analysing Structural Dependencies in Software Product Lines

Using Distribution and Network Statistics

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in cooperation with Jörg Liebig and Norbert Siegmund

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Structure of the talk

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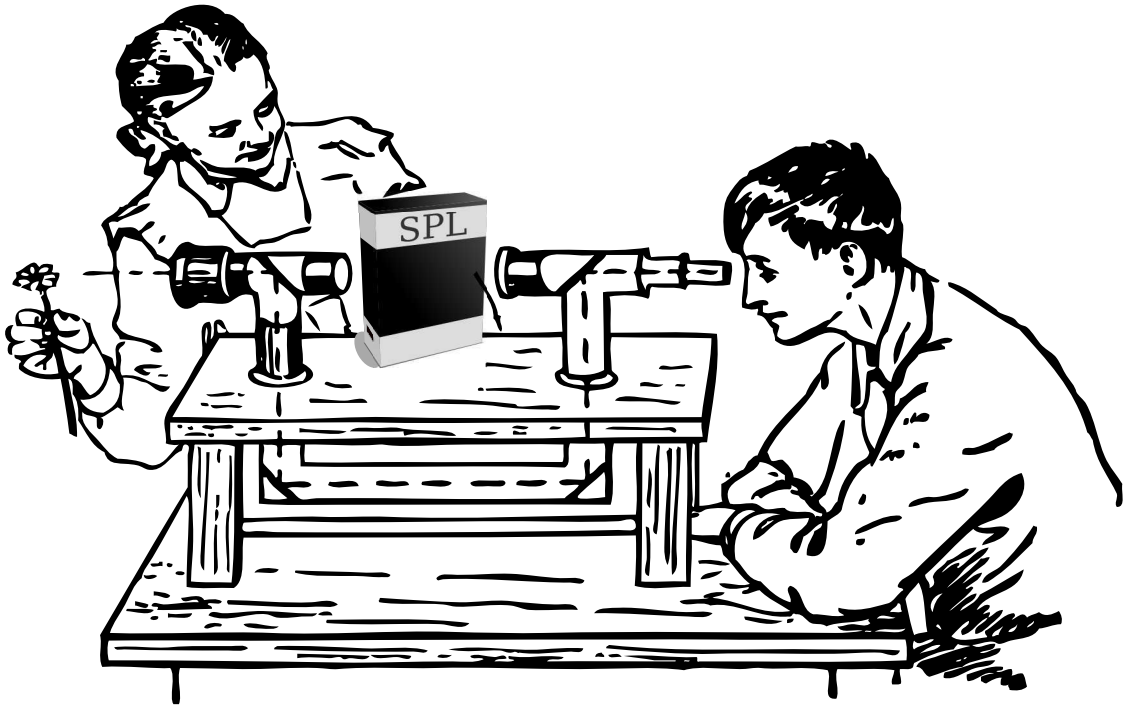
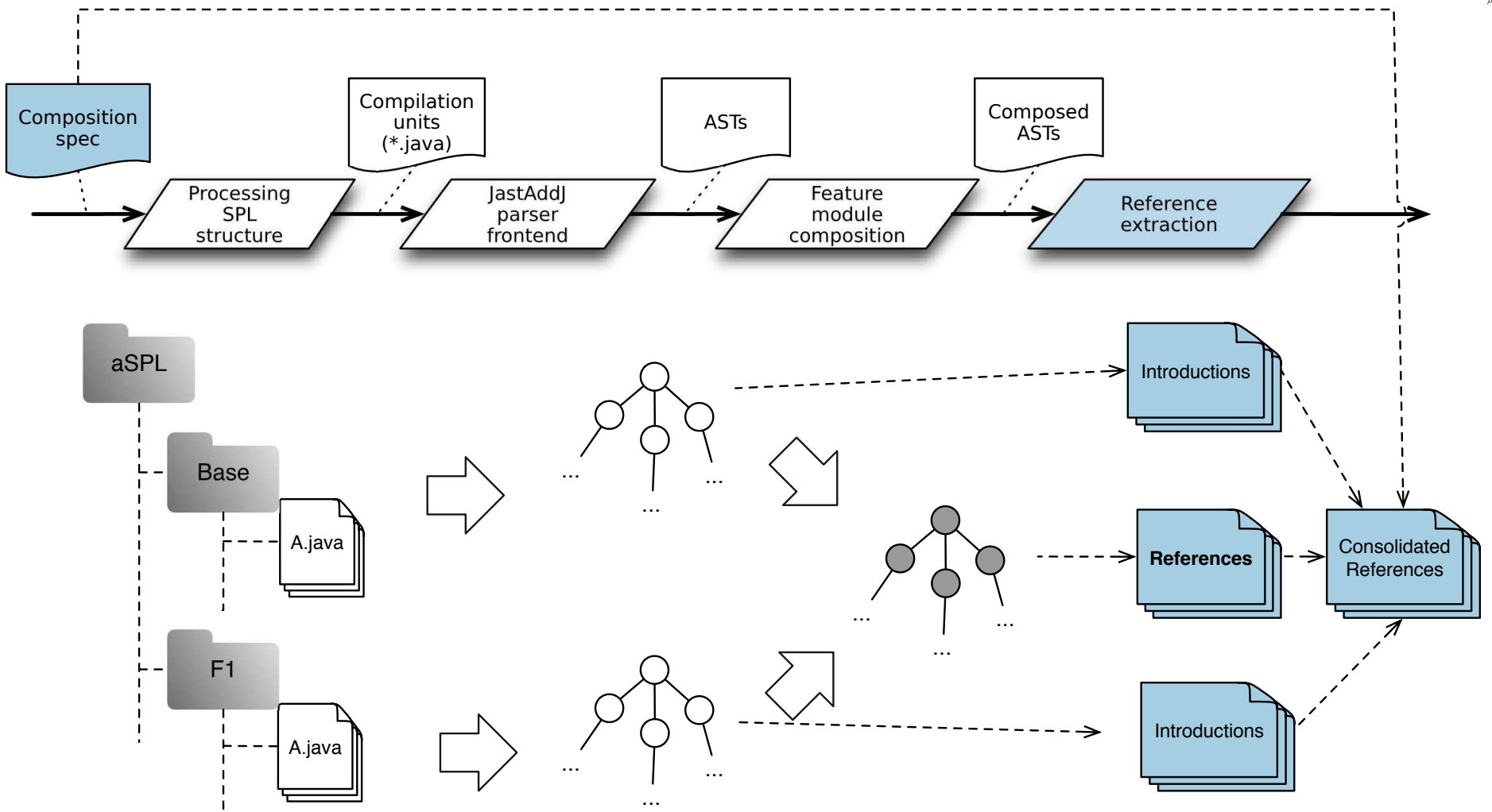
1. Motivation
2. Gathering syntactic reference data from Java-based SPLs (Fuji)
3. Notions of reference
4. Degree statistics over reference data



“Ufff! A false x-ray apparatus for SPLs?”
(Illustration adapted from Perelman (1913/2008): Physics for Entertainment, Fig. 95, p. 132)

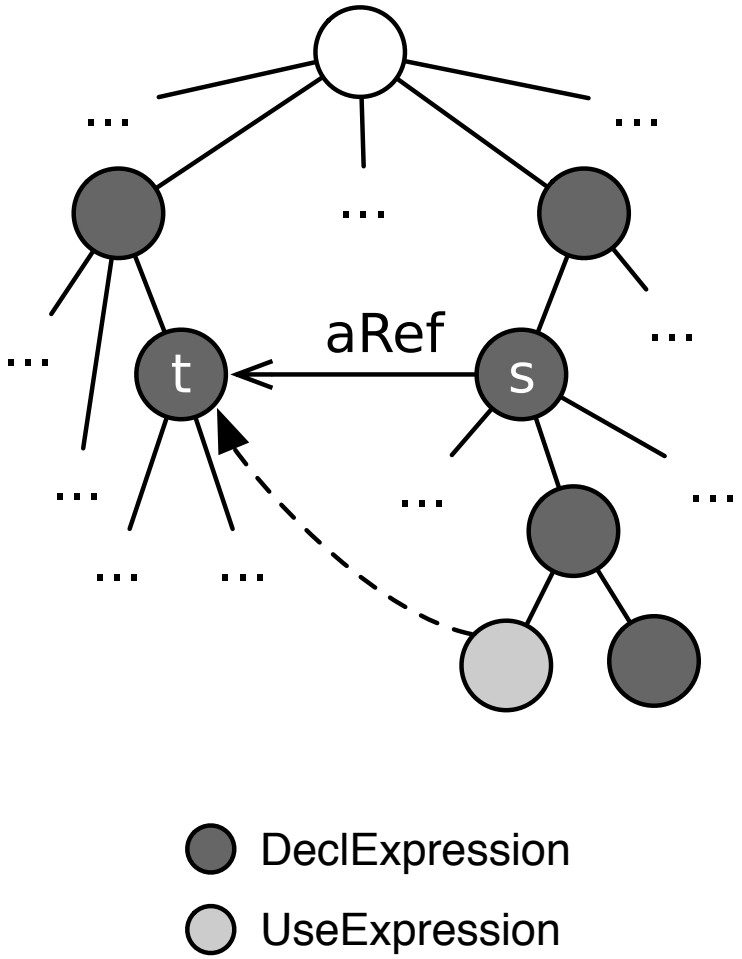
Data collection for Fuji-driven SPLs



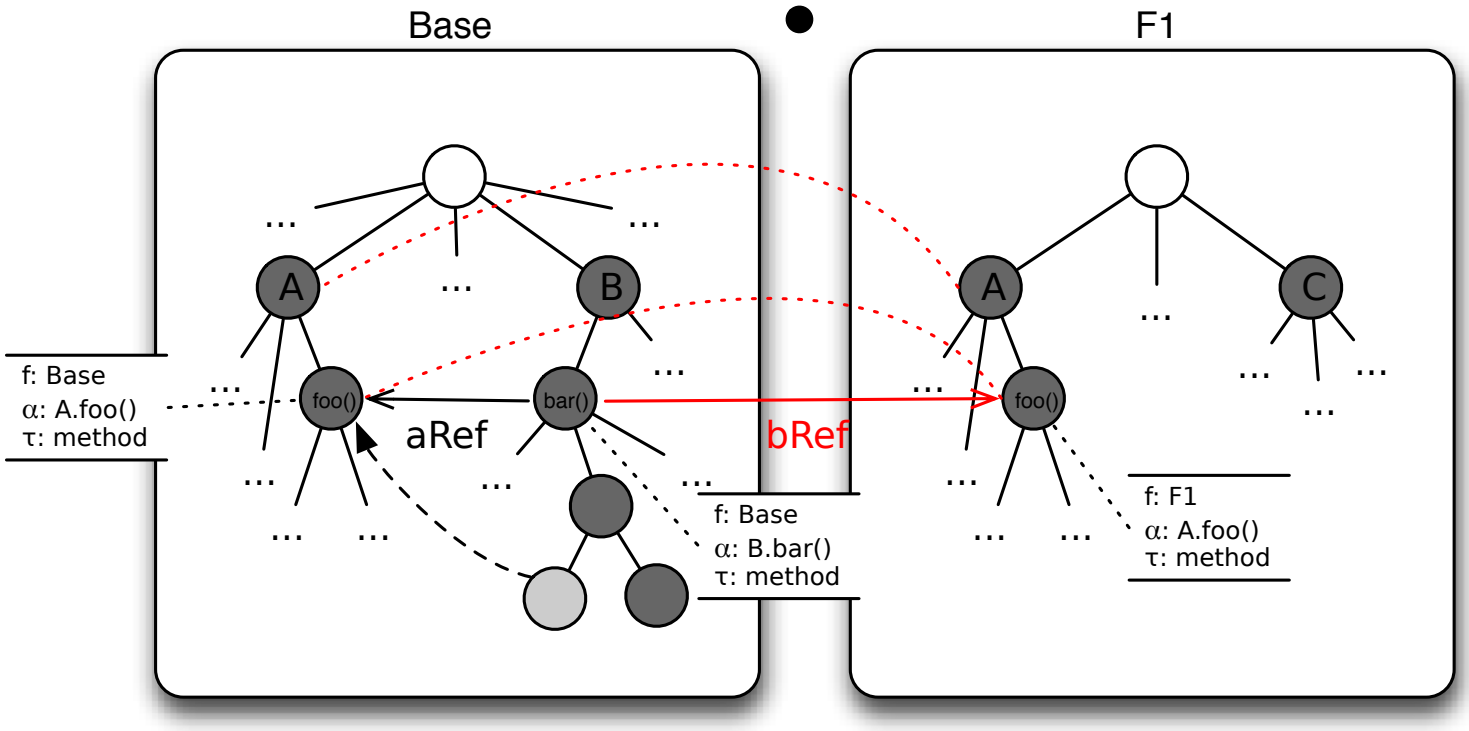
See [Kol11] for details on Fuji

A generic notion of reference

- In the Fuji/Java context, relevant `DeclExpressions` are ...
  - Class declarations
  - Constructor and initializer declarations
  - Method declarations
  - Field declarations
- Relevant `UseExpressions` are ...
  - Class-instance creation expressions
  - Field access expressions
  - Method invocation expressions



An extended notion of “Fuji reference”



$$R : F \times A \times \Gamma \mapsto F \times A \times \Gamma$$
$$= ((\{f_i, \alpha_m, \tau\}, \{f_j, \alpha_n, \tau\}), \dots)$$
$$1 \leq i, j \leq |F|,\ i \neq j$$
$$1 \leq m, n \leq |A|,\ m \neq n$$
$$\tau \in \Gamma : \{\texttt{type}, \texttt{field}, \texttt{method}, \texttt{constructor}\}$$

- Intra-module references, e.g.: `aRef`

  $(\{\texttt{Base}, \texttt{B.bar()}, \texttt{method}\}, \{\texttt{Base}, \texttt{A.foo()}, \texttt{method}\})$

- Inter-module references, e.g.: `bRef`

  $(\{\texttt{Base}, \texttt{B.bar()}, \texttt{method}\}, \{\texttt{F1}, \texttt{A.foo()}, \texttt{method}\})$

Available reference data sets (SPLs)

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- References and introductions data of **28** SPLs
- **Feature modules**: $\Delta = 99$ (BerkeleyDB) vs. $\delta = 5$ (Raroscope)
- **Introductions**: $\Delta = 9379$ (BerkeleyDB) vs. $\delta = 43$ (EPL)
- **(Unique) references**: $\Delta = 52890$ (BerkeleyDB) vs. $\delta = 80$ (EPL)
- **(Unique) inter-module references**: $\Delta = 30061$ (BerkeleyDB) vs. $\delta = 51$ (Raroscope)

Fuji reference space

The reference data can be sliced by . . .

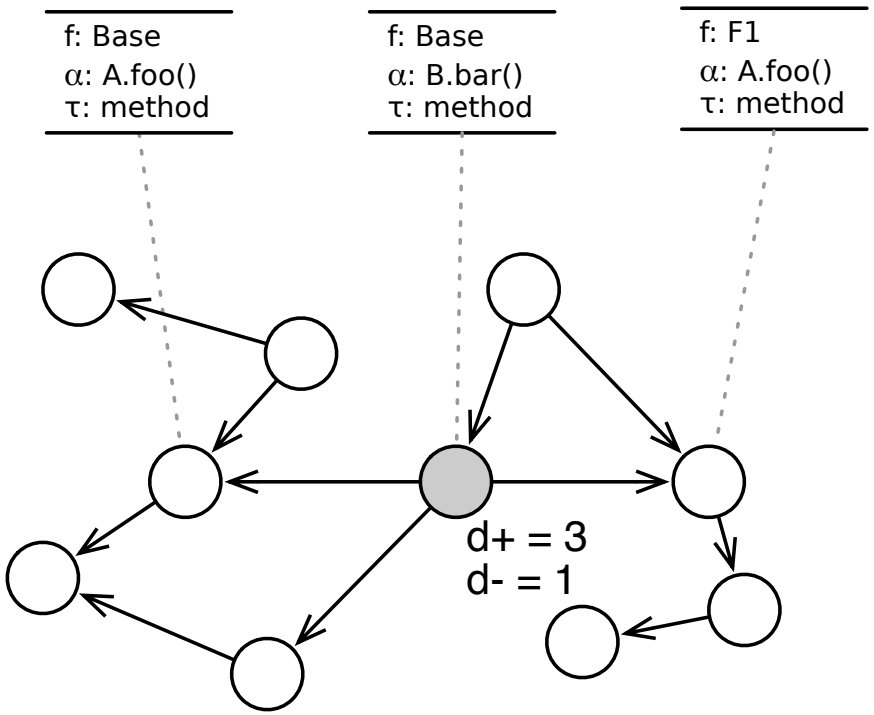
- . . . pairs of syntactic categories:

source → target	field	method	constructor	type
field				
method				
constructor				
type				

  - $4 \times 4 = 16$ subsets of reference data per SPL
  - Column-wise aggregation: field accesses, method accesses

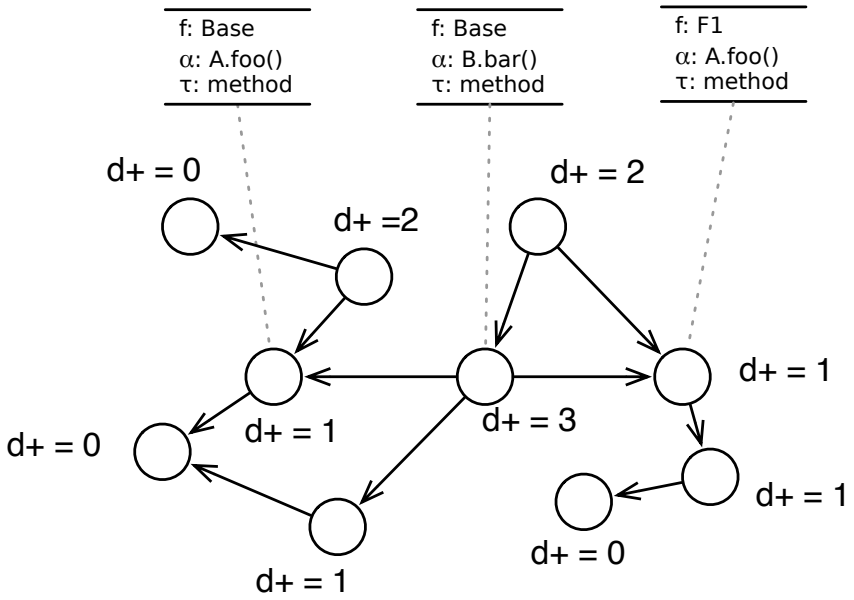
- . . . the level of abstraction: per-element vs. per-feature-module
- . . . the kind of reference: intra-module vs. inter-module
- . . . the reference direction: in- vs. outgoing
- . . . or any combination of the above!

Degrees in reference networks



- For each possible reference-data slice, e.g.:
  - method→method
  - per-element,
  - intra- and inter-module references ...
- ...we can form a graph G_R
- We can identify *local* properties of each node n (e.g., element, feature module), such as:
  - out-degree $d^+(n)$
  - in-degree $d^-(n)$
  - ...as well as their relative forms
- and *global*, degree-based characteristics
  - Average, minimum, and maximum degrees: $\phi d^+(G_R)$, $\phi d^-(G_R)$, $\Delta d^+(G_R)$, $\Delta d^-(G_R)$, $\delta d^+(G_R)$, $\delta d^-(G_R)$
  - **(In-/Out-) Degree distribution**

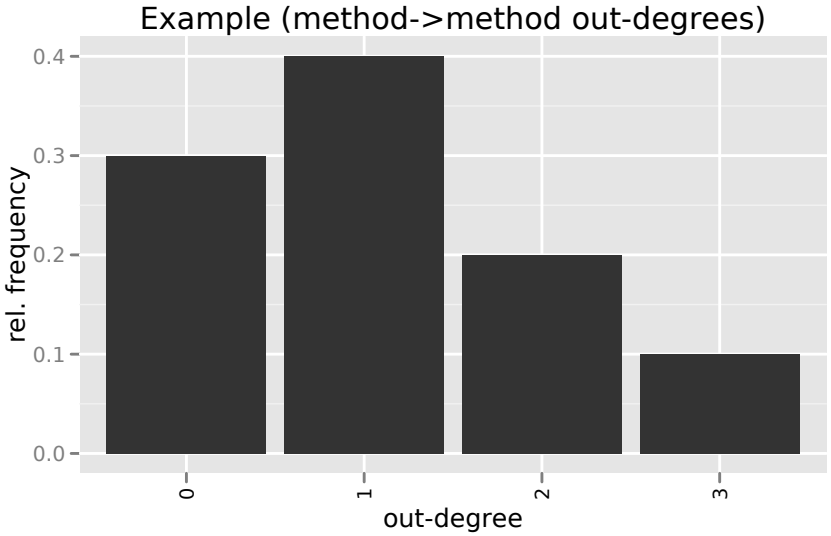
An exemplary out-degree distribution



For the given example, the *global*, out-degree characteristics are:

- $\Delta d^+(G_R) = 3$
- $\delta d^+(G_R) = 0$
- $\phi d^+(G_R) = ?$
- The distribution of out-degree frequencies in G_R:

out-degree	0	1	2	3
frequency	3	4	2	1
rel. frequency	0.3	0.4	0.2	0.1



Do degrees follow a particular distribution?

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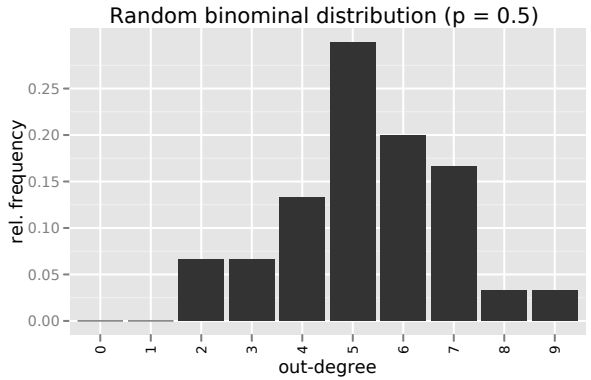

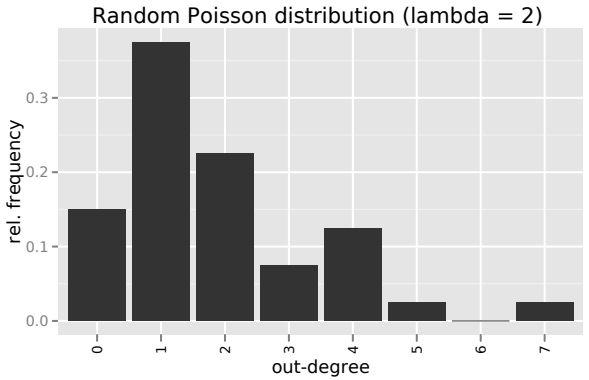

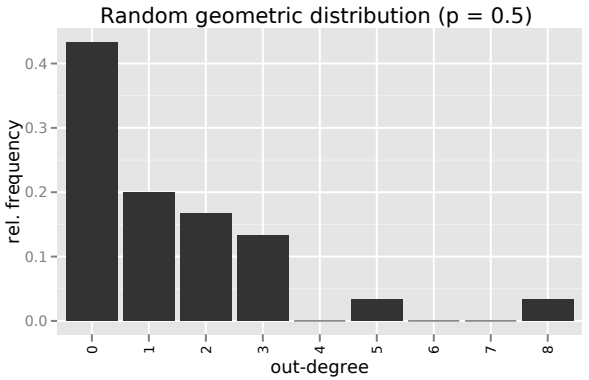

Towards Smell Detection, Ex. 1 (1)

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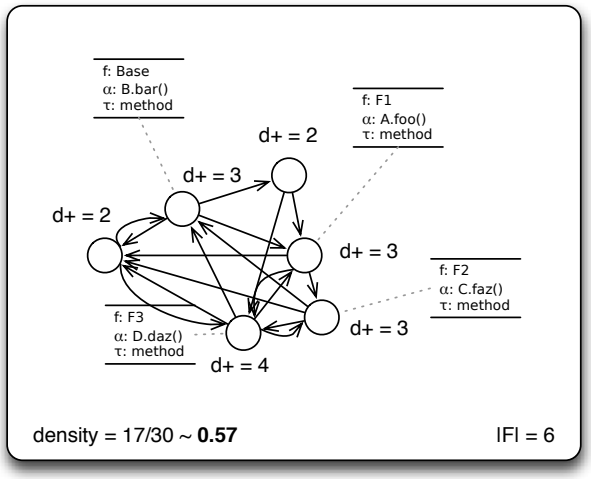
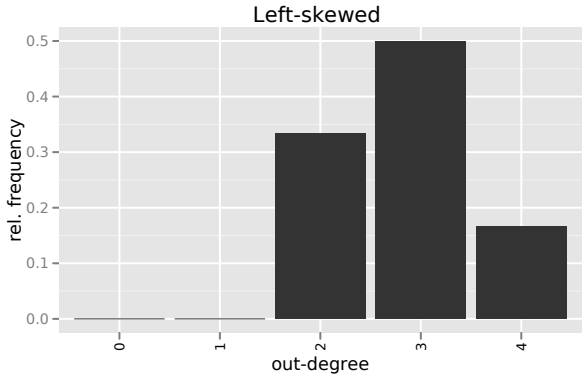
A variant of a Feature Envy [Fow03]: Excessive Inter-Module Method Invocations

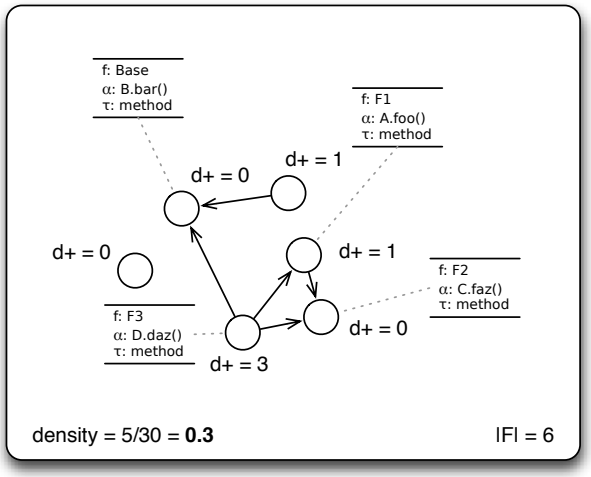
1. For a given SPL, choose the appropriate data slice: per-element, *→method references, out-degrees, inter-module
2. Indicator measures: network density, **strength** distribution (skewness)

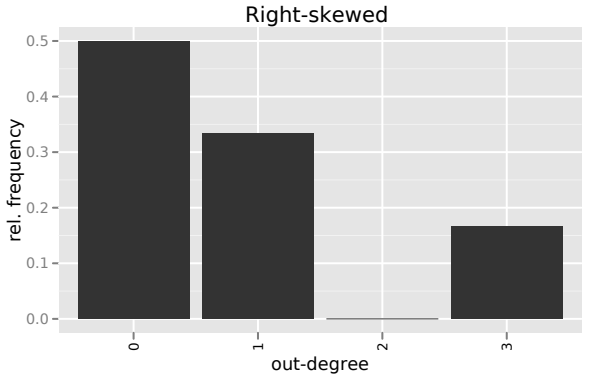
Possible envies?





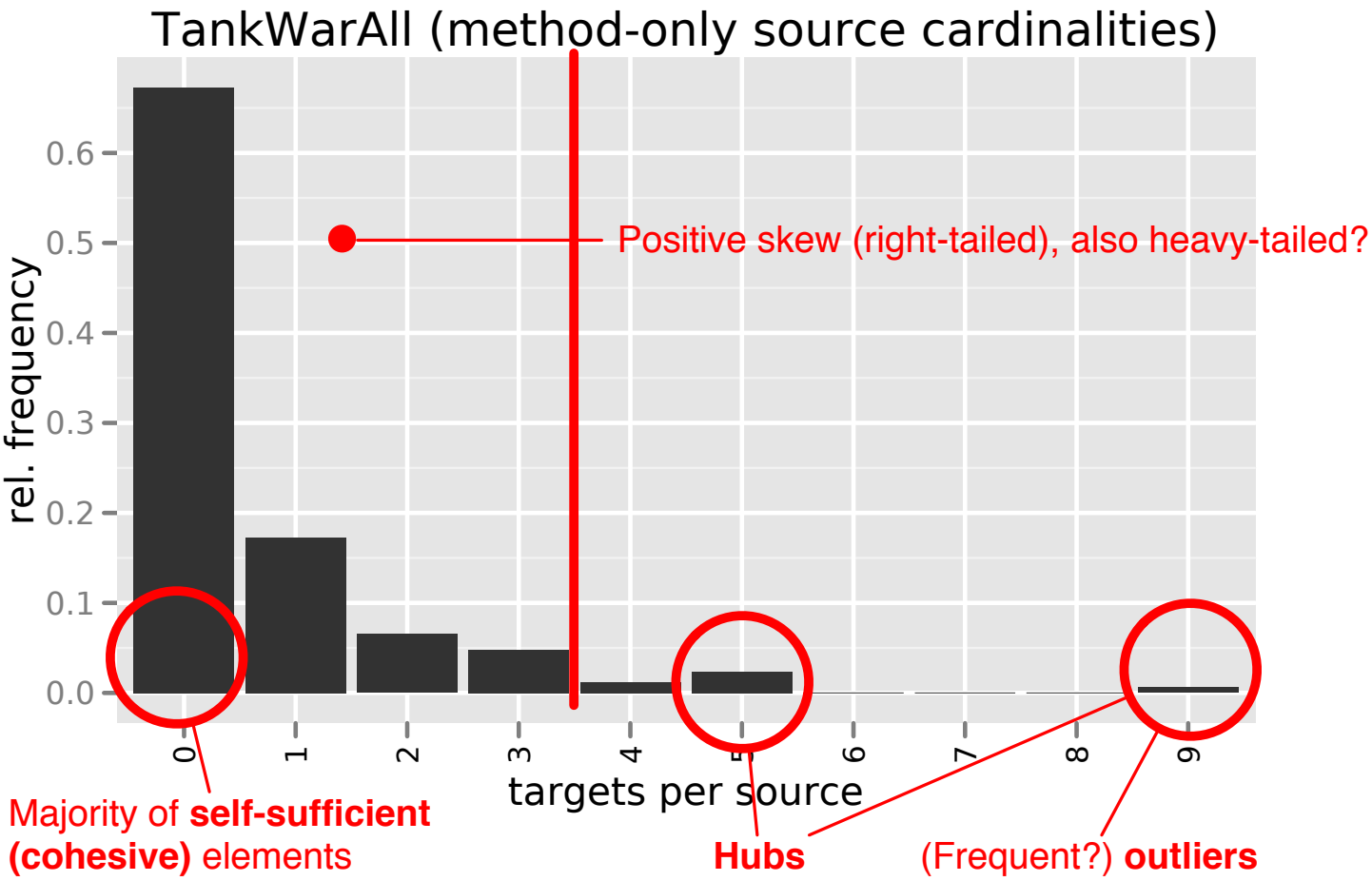
Mostly ego-centric?





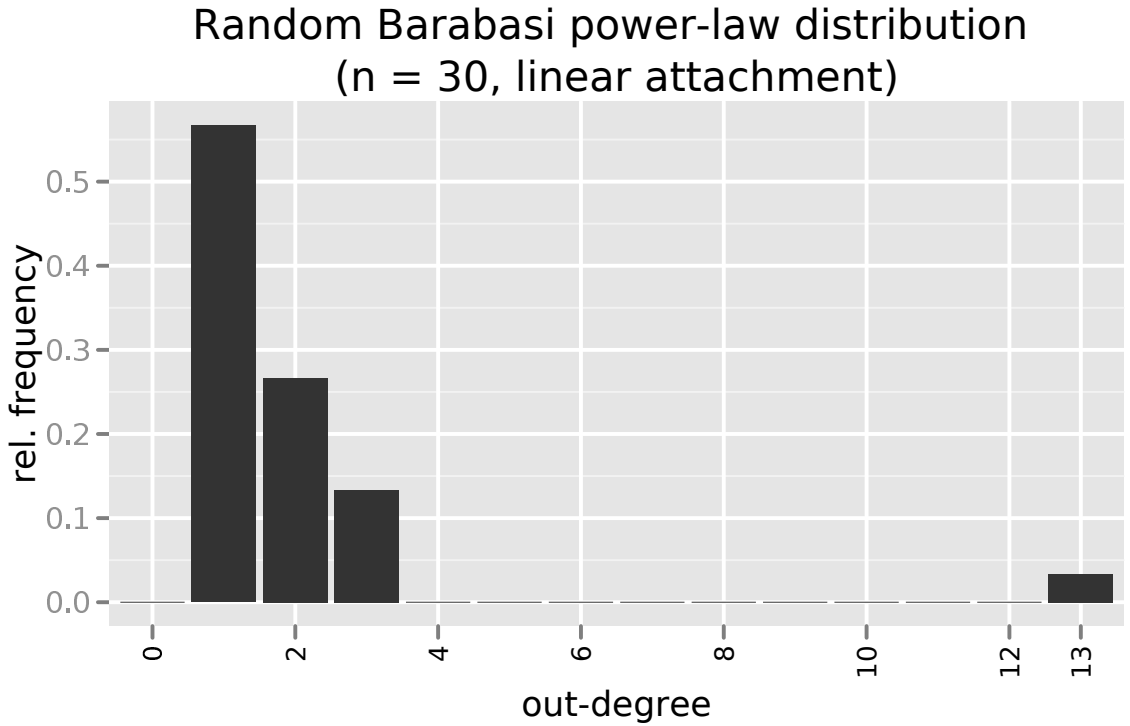
Towards Smell Detection, Ex. 1 (2)

Can one observe method-level feature Envies in the TankWar Fuji-SPL?



Research question(s): Are we looking at . . .

. . . variants of a *power-law* distribution for our SPLs and for all/certain slices?



Why would one expect to find such a degree distribution in a Fuji SPL?

On Power Laws (or the like)

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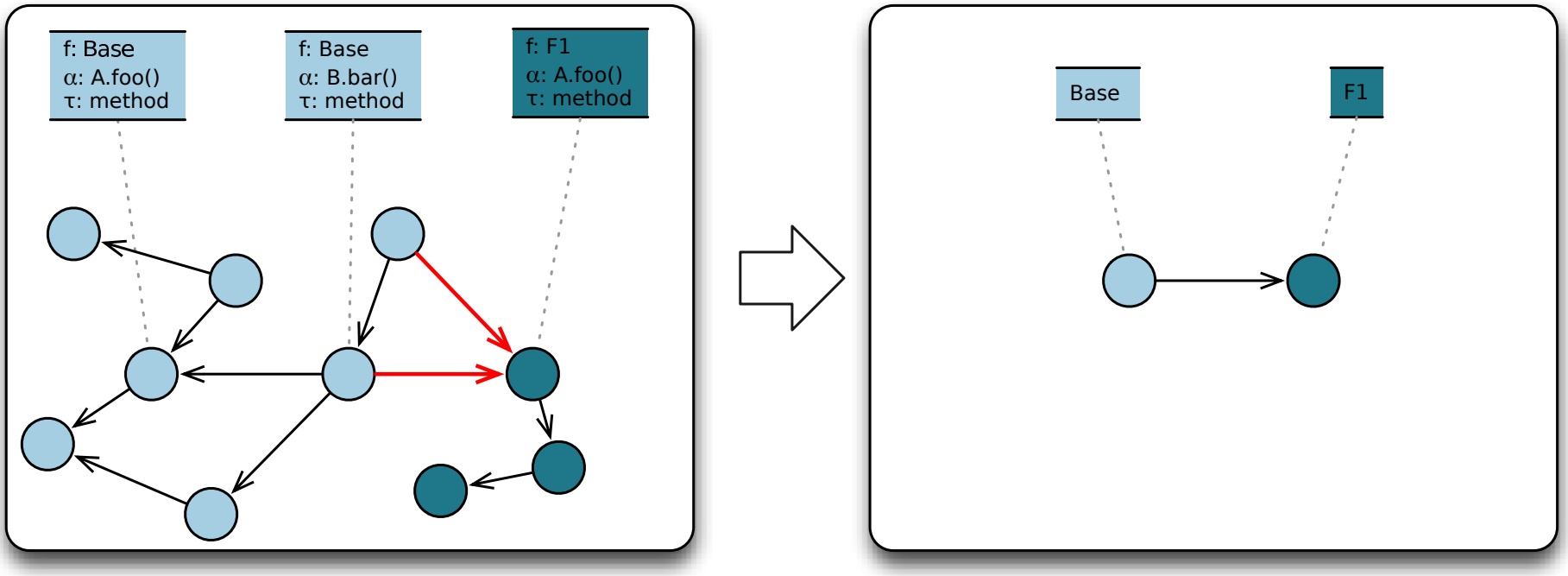
- Numerous reports for important OO program structures:
  - Many hierarchical (ownership) and non-hierarchical (statements) relations within and between class boundaries; Qualitas Corpus [TSWW11]; also states the correspondence between overall connectivity and between-class connectivity.
  - Classes and class relations such as inheritance and aggregation; JDK class libraries [WC03]
  - Variable type annotations, object creation, and parameter passing; Squeak and VisualWorks Smalltalk [MPST04].
  - Global layout of 60 object graphs, extracted from object-object references from sources as diverse as C++ frontend to GCC, the Self runtime, and Java ArgoUML [PNFB05]
- Underlying forces (development processes and practises)
  - Preferential attachment in the development process
  - OO design patterns (e.g., template & hook methods, abstract class designs)
  - Key classes

Per-feature-module statistics



- Only inter-module reference are considered
- Per-element references become aggregated/subsumed by per-module references (edge weights)

Towards Smell Detection, Ex. 2

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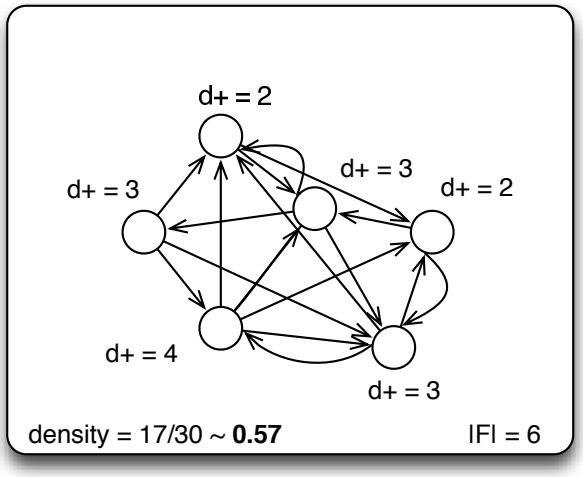
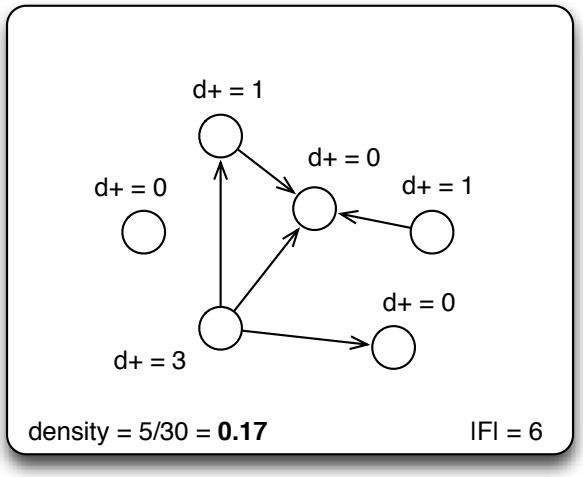
Direct Field Accesses vs. Feature-Module Boundaries [AKL+12]

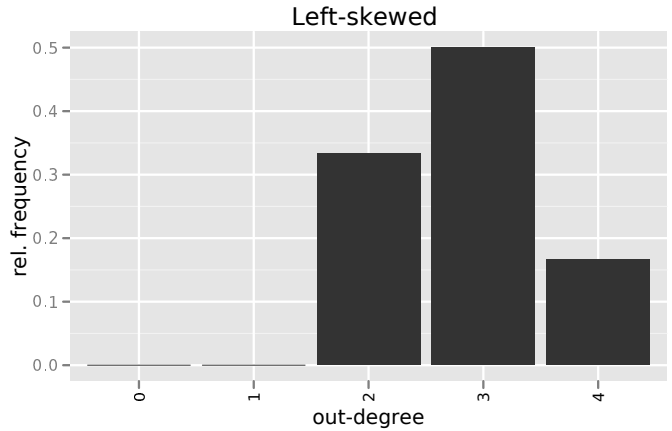
1. For a given SPL, choose the appropriate data slice: per-feature, *→field references, out-degrees, inter-module
2. Indicator measures: network density, degree distribution (skewness)

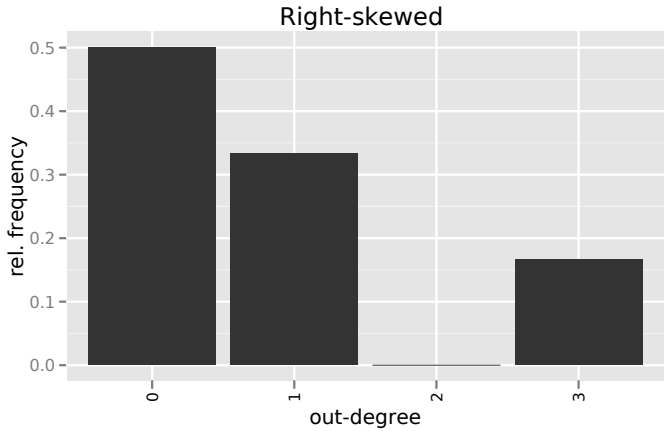
Relatively *high* coupling



Relatively *low* coupling







Closing: Further directions of analysis

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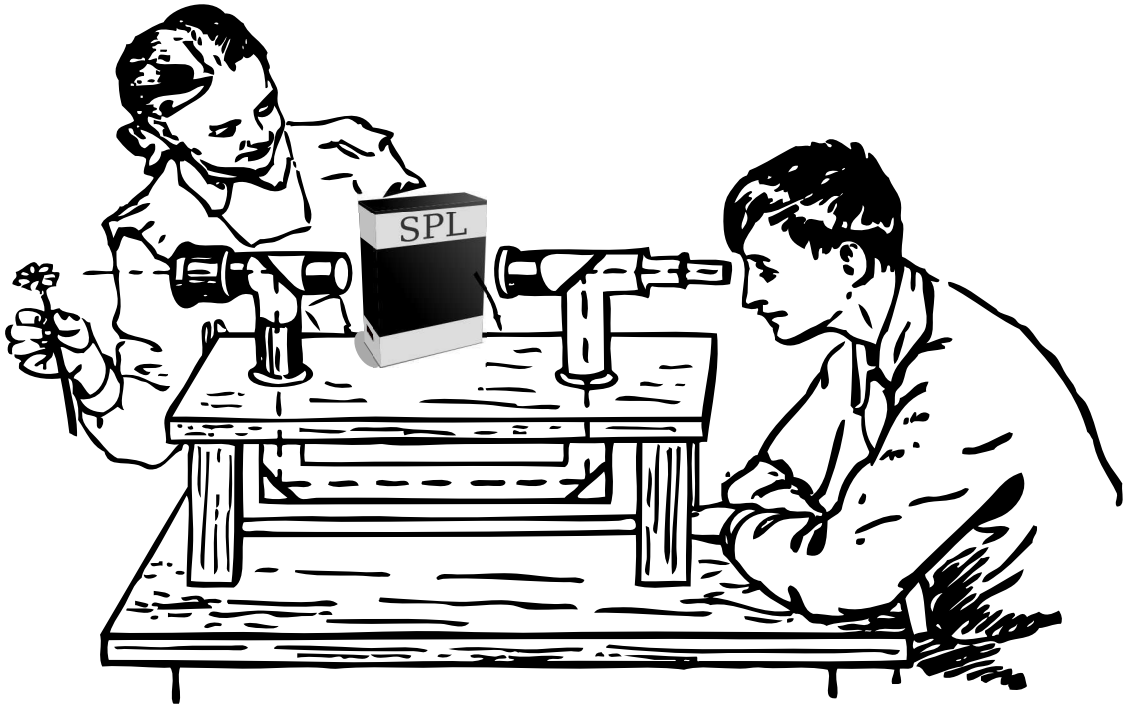
1. Short-term objectives (**Stefan**, **Sven**, **Sergiy**)
   - Additional slicing dimensions: Incorporate co-occurrence dependencies between feature modules (never, always, optional)
   - Usage frequencies of introductions
   - Distribution statistics for field and method accesses per feature module
   - Local/global characteristics of *derivative* features (**Jörg**)
   - Detection/calibration of *intrinsic* (statistical) thresholds for degree and distribution statistics
   - Input for Performance Prediction (see **Norbert**'s and **Sergiy**'s talks): Higher-Order (e.g., triangles) and Hot-Spot Features (hubs, betweeness)
2. Mid-term objectives
   - Detection/calibration of *extrinsic* thresholds, by incorporating the non-functional data profiles of the SPLs (**Sergiy**, **Norbert**, **Jörg**)
   - Weighted network statistics (**Stefan**, **Sven**, **Jörg**)
     - Edge weights based on reference counts (per-element, per-feature)
     - Attribute measures as edge weights (e.g., degrees of coupling and scattering, . . .)
     - . . .

Shooting time!



“What do you see through the walls of SPL code data?”
(Illustration adapted from Perelman (1913/2008): Physics for Entertainment, Fig. 95, p. 132)

References

- Sergiy Kolesnikov. Ein erweiterbarer Compiler zum feature-orientierten Programmieren in Java. Talk at the FOSD Annual Meeting 2011, Dresden, März 2011
- Craig Taube-Schock, Robert Walker, and Ian Witten. Can we avoid high coupling? In *ECOOP 2011 – Object-Oriented Programming*, volume 6813 of *Lecture Notes in Computer Science*, pages 204–228. Springer-Verlag, 2011
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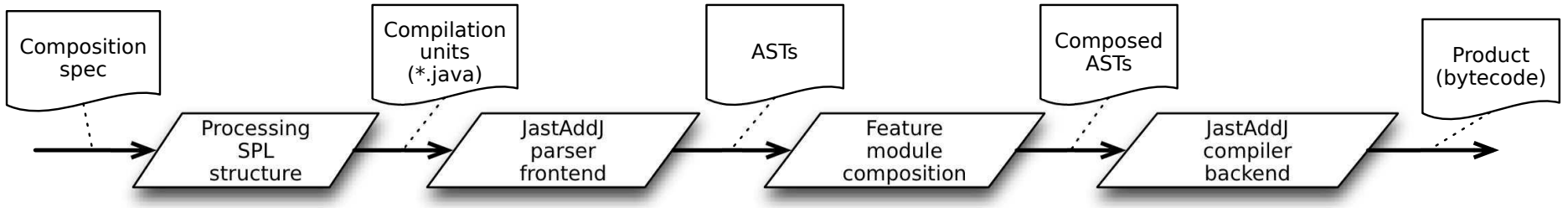
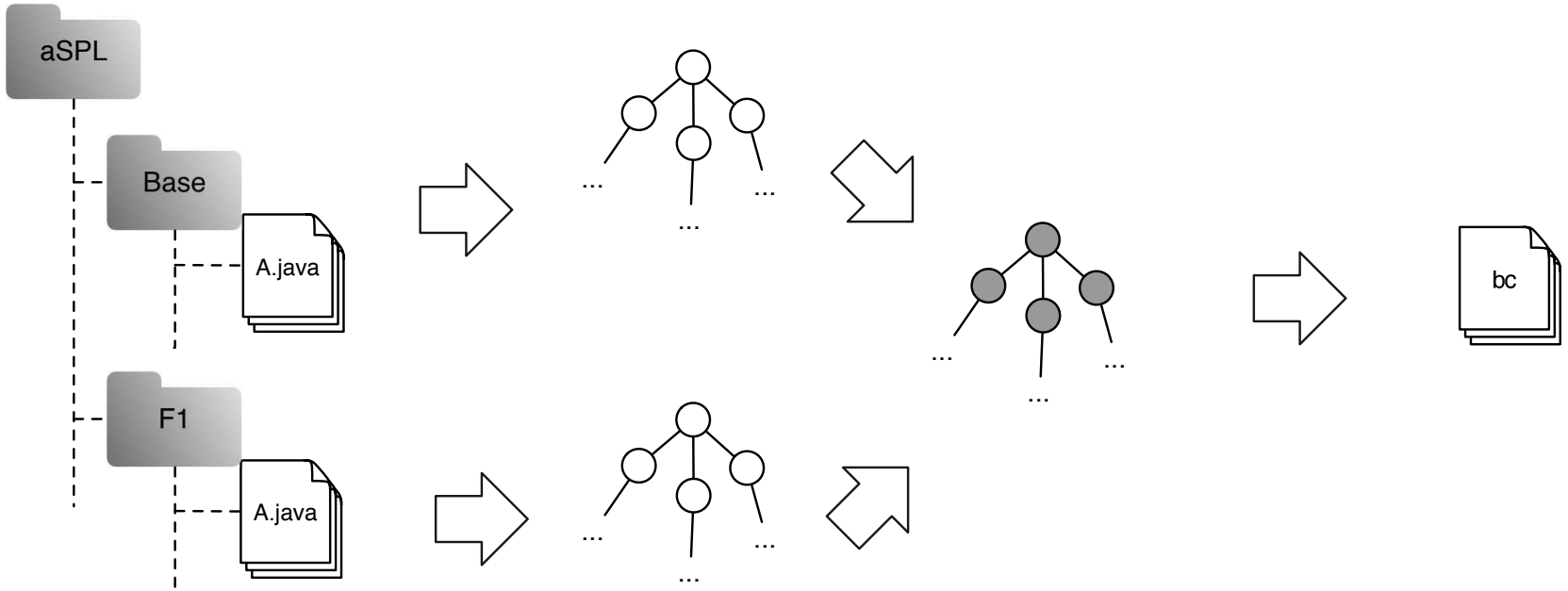
Appendix

Fuji-driven SPLs

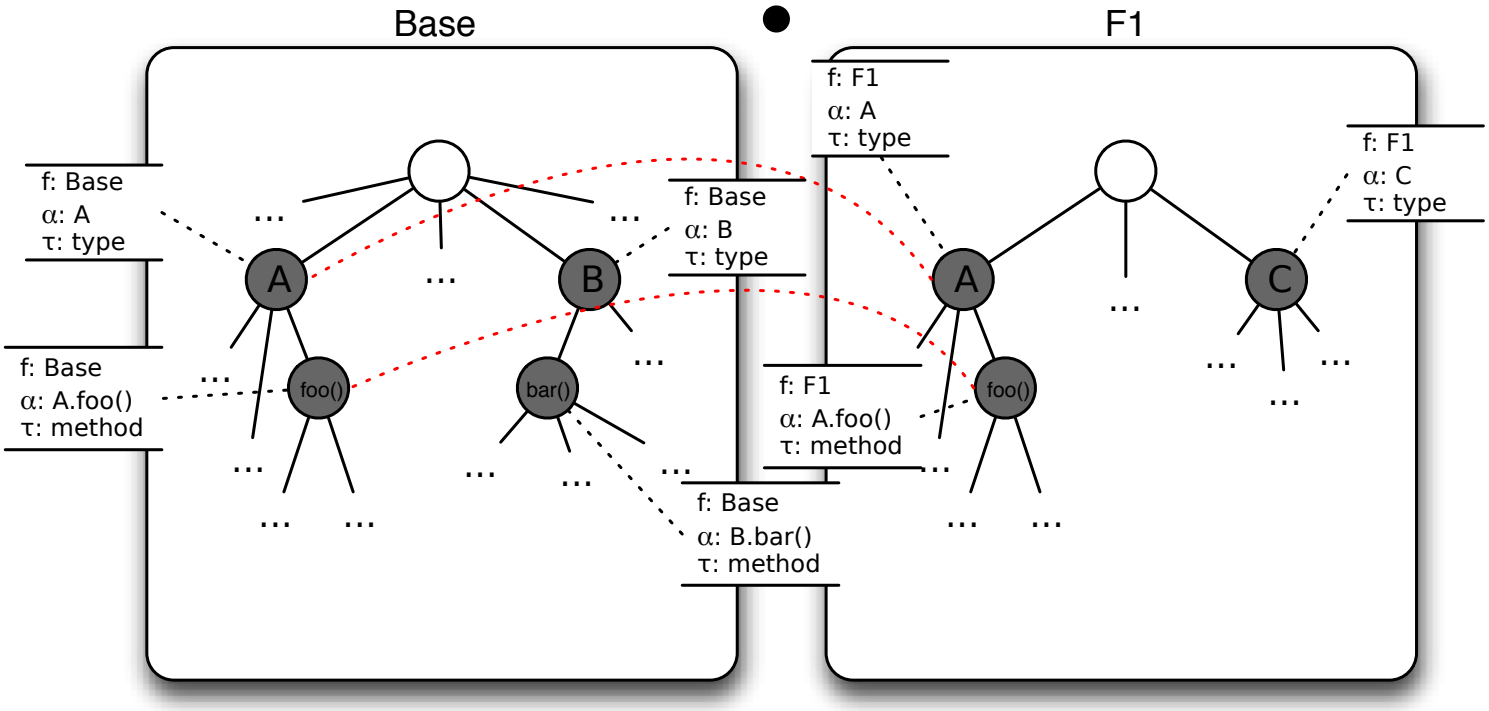




See [Kol11] for details on Fuji

Feature-module composition

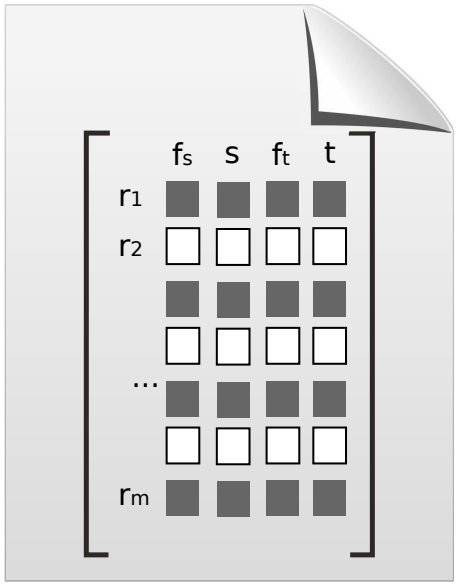
Fuji composes feature modules using AST superimposition: $Base \bullet F1$



Each declaration element are identified by ...

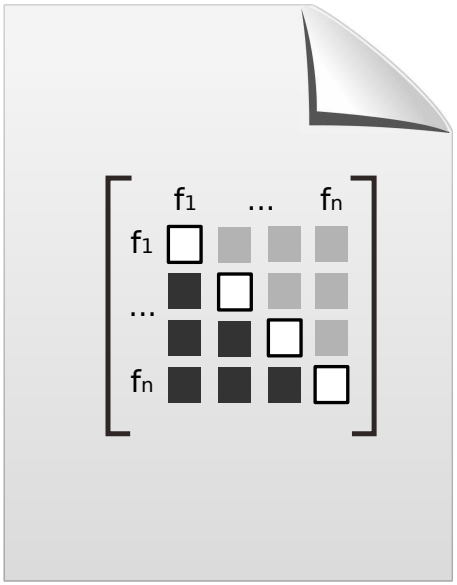
- ... its introducing feature module f: `Base`, `F1`
- ... its label α: `A`, `B`, ..., `foo()`
- ... its syntactic category τ: `type`, `method`

Exploratory issue: Per-feature-module statistics (1)



Reference data
(showing source and target feature per reference)

cross-tabulation



Asymmetric feature-feature matrix