

# Figaro Release Notes

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## About Figaro

Reasoning under uncertainty requires taking what you know and inferring what you don't know, when what you know doesn't tell you for sure what you don't know. A well-established approach for reasoning under uncertainty is probabilistic reasoning. Typically, you create a probabilistic model over all the variables you're interested in, observe the values of some variables, and query others. There is a huge variety of probabilistic models, and new ones are being developed constantly. Figaro is designed to help build and reason with the wide range of probabilistic models.

Developing a new probabilistic model normally requires developing a representation for the model and a reasoning algorithm that can draw useful conclusions from evidence, and in many cases also an algorithm to learn aspects of the model from data. These can be challenging tasks, making probabilistic reasoning require significant effort and expertise. Furthermore, most probabilistic reasoning tools are standalone and difficult to integrate into larger programs.

Figaro is a probabilistic programming language that helps address both these issues. Figaro makes it possible to express probabilistic models using the power of programming languages, giving the modeler the expressive tools to create all sorts of models. Figaro comes with a number of built-in reasoning algorithms that can be applied automatically to new models. In addition, Figaro models are data structures in the Scala programming language, which is interoperable with Java, and can be constructed, manipulated, and used directly within any Scala or Java program.

Figaro is extremely expressive. It can represent a wide variety of models, including:

- directed and undirected models
- models in which conditions and constraints are expressed by arbitrary Scala functions
- models involving inter-related objects
- open universe models in which we don't know what or how many objects exist
- models involving discrete and continuous elements
- models in which the elements are rich data structures such as trees
- models with structured decisions
- models with unknown parameters

Figaro provides a rich library of constructs to build these models, and provides ways to extend this library to create your own model elements.

Figaro's library of reasoning algorithms is also extensible. Current built-in algorithms include:

- Exact inference using variable elimination
- Belief propagation
- Lazy factored inference for infinite models

- Importance sampling
- Metropolis-Hastings, with an expressive language to define proposal distributions
- Support computation
- Most probable explanation (MPE) using variable elimination or simulated annealing
- Probability of evidence using importance sampling
- Particle Filtering
- Factored frontier
- Parameter learning using expectation maximization

Figaro provides both regular (the algorithm is run once) and anytime (the algorithm is run until stopped) versions of some of these algorithms. In addition to the built-in algorithms, Figaro provides a number of tools for creating your own reasoning algorithms.

Figaro is free and is released under an open-source license (see license file). The public code repository for Figaro can also be found at <https://github.com/p2t2>

## What's New in Figaro 3.0?

Many new features have been introduced into Figaro 3.0 since Figaro 2.0 was released. These include:

- A collections library. This library includes support for processes defined over an infinite space, such as Gaussian processes or continuous-time Markov processes. It also supports collections consisting of an unknown number of elements. Many convenient methods are defined on Figaro collections, including mapping values of elements in a collection through a function and folds or aggregates (for finite collections).
- A number of new algorithms:
  - Lazy variable elimination allows variable elimination to be used on very large or infinite models by only expanding part of the model and quantifying the contribution of the unexpanded part of the model on the query.
  - Belief propagation for approximate factored inference.
  - The factored frontier algorithm for filtering.
  - A wider variety of expectation-maximization-based learning algorithms.
- Improvements to existing algorithms:
  - Forward sampling algorithms like importance sampling and particle filtering now work in log space to avoid underflow.
  - Importance sampling now properly implements likelihood weighting to avoid too many rejections.
  - More algorithms support computing probability of evidence, including variable elimination, importance sampling, and particle filtering.
  - Observations on continuous elements are now implemented as constraints on the arguments of the elements, which helps avoiding rejections and mixing.
  - Ability to sample particular target variables without sampling all the variables.
- Features to make programming easier:

- New patterns for learning. Parameter collections enable you to reuse the same parameters in both the training model and operational model.
- One line shortcuts for common queries.
- Ability to query the mean and variance of a Double element.
- Ability to add logarithmic constraints to elements.
- New element classes in the library:
  - Multivariate normal
  - Inverse gamma
  - Parameterized binomial
  - Fold for implementing associative aggregates efficiently
- Numerous minor improvements and bug fixes

## Where can I get Figaro binary distributions?

The latest stable Figaro binary release is available for download from the Charles River Analytics, Inc. Web site:

<http://www.cra.com/figaro>

Each binary release comes with Figaro, all required libraries, Scaladoc, examples, and source code.

## How do I run the Figaro Examples?

The easiest way to run the Figaro examples is to install Scala and use the latest Figaro binary release.

To get started, download Scala from <http://scala-lang.org/download/>. You will need Scala version 2.11.2 or later to run the latest Figaro release. Follow the Scala installation instructions at <http://scala-lang.org/download/install.html> and make sure you can run, compile, and execute the “Hello World” program provided in the documentation.

The next step is to obtain Figaro. The Figaro binary distribution is hosted at the Charles River Analytics, Inc. Web site at <https://www.cra.com/figaro>. The current version, as of May 2015, is 3.1.0.0 and is available for Scala 2.11. Make sure the Figaro version you use matches the Scala version. Each available download link is a compressed archive containing the Figaro jar (jar is the Java/Scala format for compiled byte code), examples, documentation, Scaladoc, and source code files. Click the appropriate link and then uncompress the downloaded archive to access the files. In each distribution, you will find a Figaro jar with a name ending with “fat” (such as “figaro\_2.11-3.1.0.0-fat.jar”), indicating that this is a fat jar containing all the necessary libraries to run Figaro.

The final step is to open a command prompt and switch to the uncompressed Figaro download directory. Using the Scala command line program, run any Figaro example by setting the Scala classpath and invoking the desired class:

```
scala -cp figaro_2.11-3.1.0.0-fat.jar;figaroexamples_2.11-3.1.0.0.jar <example_class>
```

For example, to run the Burglary program:

```
scala -cp figaro_2.11-3.1.0.0-fat.jar;figaroexamples_2.11-3.1.0.0.jar com.cra.figaro.example.Burglary
```

## What Figaro Example classes are available?

The following examples are available in the Figaro Examples JAR file included in the binary release:

```
com.cra.figaro.example.AnnealingSmokers
com.cra.figaro.example.Burglary
com.cra.figaro.example.CarAndEngine
com.cra.figaro.example.CoinExample
com.cra.figaro.example.DiceExample
com.cra.figaro.example.Entrepreneur
com.cra.figaro.example.Firms
com.cra.figaro.example.Hierarchy
com.cra.figaro.example.LazyList
com.cra.figaro.example.MultiDecision
com.cra.figaro.example.MultiValuedReferenceUncertainty
com.cra.figaro.example.MutableMovie
com.cra.figaro.example.OpenUniverse
com.cra.figaro.example.OpenUniverseLearning
com.cra.figaro.example.SimpleLearning
com.cra.figaro.example.SimpleMovie
com.cra.figaro.example.Smokers
com.cra.figaro.example.Sources
com.cra.figaro.example.ValveReliability
com.cra.figaro.example.dosage.DosageDecision
com.cra.figaro.example.graph.GraphDecision
```

## How do I run my own Figaro programs?

The simplest way to compile and run the Figaro programs you create is to use the Simple Build Tool (SBT) program and the FigaroWork project.

FigaroWork is an SBT project that enables users to quickly start writing their own Figaro programs. The project is set up to automatically pull in the relevant versions of Scala and Figaro, so there is nothing else for you to install. SBT also makes sure the Scala classpath is configured correctly for your project, saving you some hassle when running your programs.

To get started, download and uncompress the FigaroWork files to a directory on your machine. The FigaroWork project is hosted at the Charles River Analytics, Inc. Web site at <https://www.cra.com/figaro>. Then download the latest release of SBT v0.13 for your operating system at <http://www.scala-sbt.org/download.html> and install it following these guidelines <http://www.scala-sbt.org/0.13/tutorial/Manual-Installation.html>.

When you have finished installing, you will have the following directories and files on your machine:

```

\FigaroWork
  README.txt
  \project
    build.properties
    Build.scala
    plugins.sbt
  \src
    \main
      \scala
        Test.scala

```

Test your new build environment by running the simple Figaro test program provided with the project. Open a command prompt, navigate to your local FigaroWork directory (ex. C:\FigaroWork), and run this command

```
sbt "runMain Test"
```

This command tells SBT to compile the Scala files in the project and execute the main() method of the Test class. Remember to include the quotes around the runMain command. You should see output similar to this

```

[info] Running Test
1.0

```

Now you can copy your existing Figaro program packages and Scala source files to

```
\FigaroWork\src\main\scala
```

or create new ones there. Run your Figaro program like this

```
sbt "runMain <class_with_main> <parameters>"
```

Replace <class\_with\_main> with the package and class that contains the main() method that starts your Figaro program. Replace <parameters> with the list of command line parameters (if any) your program may need to run. For example

```
sbt "runMain com.cra.test.FigaroTest parameter1 parameter2 parameter3"
```

## How do I run my own Figaro programs without SBT?

While SBT is a useful tool, you may want to manage your own workspace differently.

To run Figaro, you will first need Scala. The Scala compiler can either be run from the command line or within an Integrated Development Environment (IDE). Two IDEs that support Scala development are Eclipse and IntelliJ Idea. NetBeans also has a Scala plugin but it does not appear to support recent versions of Scala (but that may have changed). This section focuses on how to obtain Scala and Figaro

and run Scala programs that use Figaro from the command line. If you choose to use an IDE, please see the documentation of your IDEs and Scala plugins for details of how to include the Figaro library.

To get started, download Scala from <http://scala-lang.org/download/>. You will need Scala version 2.11.2 or later to run the latest version of Figaro. Follow the Scala installation instructions at <http://scala-lang.org/download/install.html> and make sure you can run, compile, and execute the “Hello World” program provided in the documentation.

The next step is to obtain Figaro. The Figaro binary distribution is hosted at the Charles River Analytics, Inc. Web site. Go to <https://www.cra.com/figaro>. The current version, as of May 2015, is 3.1.0.0, and is available for Scala 2.11. Always make sure the Figaro version you use matches the Scala version you’re using. Each available download link is a compressed archive containing the Figaro jar (jar is the Java/Scala format for compiled byte code), examples, documentation, Scaladoc, and source code files. Click the appropriate link and then uncompress the downloaded archive to access the Figaro jar file. In the distribution, the Figaro jar name ends with “fat”, indicating that this is a fat jar containing all the necessary libraries to run Figaro. Using a fat jar simplifies the Scala classpath needed to run Figaro programs.

Optionally, you can add the fully qualified path name of the Figaro jar to your classpath. This can be done by adding the Figaro jar to the CLASSPATH environment variable in your operating system. The process for editing the CLASSPATH varies from operating system to operating system. You can see details about using the PATH and CLASSPATH environment variables in <http://docs.oracle.com/javase/tutorial/essential/environment/paths.html>.

If the CLASSPATH does not exist yet, create it. It is good practice to include the current working directory, so set the CLASSPATH to “.”, then proceed to add the Figaro jar, as in the next step.

By this point, the CLASSPATH already exists, so we can add the Figaro path to it. For example, on Windows 7, if figaro\_2.11-3.1.0.0-fat.jar is in the “C:\Users\apfeffer” folder and the CLASSPATH is currently equal to “.”, change the CLASSPATH to “C:\Users\apfeffer\figaro\_2.11-3.1.0.0-fat.jar;.” (replace 3.1.0.0 with the appropriate Figaro version number).

Now you can compile and run Figaro programs just like any Scala program. Put the Test program below in a file named Test.scala. First, let’s assume you followed step 4 and updated the CLASSPATH.

If you run scala Test.scala from the directory containing Test.scala, the Scala compiler will first compile the program and then execute it. It should produce the output 1.0.

If you run scalac Test.scala (note the c at the end of “scalac”), the Scala compiler runs and produces .class files. You can then execute the program by running scala Test from the same directory.

If you did not follow step 4, you can set the CLASSPATH from the command line using the -cp option. For example, to compile and execute Test.scala, assuming figaro\_2.11-3.1.0.0-fat.jar is in the “C:\Users\apfeffer” folder, you can run

```
scala -cp C:\Users\apfeffer\figaro_2.11-3.1.0.0-fat.jar Test.scala
```

Here's the Test program:

```
import com.cra.figaro.language._
import com.cra.figaro.algorithm.sampling._

object Test {
  def main(args: Array[String]) {
    val test = Constant("Test")
    val algorithm = Importance(1000, test)
    algorithm.start()
    println(algorithm.probability(test, "Test"))
  }
}
```

This program should output 1.0 when run.

## How do I compile Figaro from source code?

Figaro is maintained as open source on GitHub. The GitHub project is Probabilistic Programming Tools and Techniques (P2T2), located at <https://github.com/p2t2>. P2T2 currently contains the Figaro sources, but we plan to update it with more tools. If you want to see the source code and build Figaro yourself, please visit our GitHub site.

To build Figaro from GitHub source, make a fork of the Figaro repository to your GitHub account, then use git's clone feature to get the source code from your GitHub account to your machine.

```
git clone https://github.com/[your-github-username]/figaro.git
```

There are several branches available; checkout "master" for the latest stable release or the latest "DEV" branch for more cutting edge work and features (this is work in progress and therefore less stable).

Figaro uses Simple Build Tool (SBT) to manage builds, located at <http://www.scala-sbt.org/>. Download and install SBT, open a command prompt, switch to your newly cloned local Figaro directory, and enter this SBT command set:

```
sbt clean compile package publishLocal assembly copy-deps
```

This will create Figaro for Scala 2.11; you will find the resulting artifacts in the "target" directory.

To run the Figaro unit tests, use this SBT command

```
sbt test
```

Note that some of the unit tests may not always pass because their results are non-deterministic.

## How can I use Figaro in my project?

If you wish to integrate Figaro's features into your own software project, Figaro is available on Maven Central (<http://search.maven.org>). Shown below are a few examples of how you can add Figaro as a dependency to your existing project:

### *Simple Build Tool (SBT) Projects*

```
libraryDependencies += "com.cra.figaro" %% "figaro" % "3.1.0.0"
```

### *Apache Maven Projects*

```
<dependency>  
  <groupId>com.cra.figaro</groupId>  
  <artifactId>figaro_2.11</artifactId>  
  <version>3.1.0.0</version>  
</dependency>
```

### *Apache Ivy Projects*

```
<dependency org="com.cra.figaro" name="figaro_2.11" rev="3.1.0.0" />
```