http://en.wikipedia.org/wiki/Inverse\_Gaussian\_distribution

**Inverse Gaussian distribution**

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|  |  |
| --- | --- |
| Inverse Gaussian | |
| Probability density function  [PDF invGauss.svg](http://en.wikipedia.org/wiki/File:PDF_invGauss.svg) | |
| **Parameters** | \lambda > 0   \mu > 0 |
| [**Support**](http://en.wikipedia.org/wiki/Support_%28mathematics%29) | x \in (0,\infty) |
| [**pdf**](http://en.wikipedia.org/wiki/Probability_density_function) | \left[\frac{\lambda}{2 \pi x^3}\right]^{1/2} \exp{\frac{-\lambda (x-\mu)^2}{2 \mu^2 x}} |
| [**CDF**](http://en.wikipedia.org/wiki/Cumulative_distribution_function) | \Phi\left(\sqrt{\frac{\lambda}{x}} \left(\frac{x}{\mu}-1 \right)\right) +\exp\left(\frac{2 \lambda}{\mu}\right) \Phi\left(-\sqrt{\frac{\lambda}{x}}\left(\frac{x}{\mu}+1 \right)\right)  where  \Phi \left(\right)is the [standard normal (standard Gaussian) distribution](http://en.wikipedia.org/wiki/Normal_distribution) c.d.f. |
| [**Mean**](http://en.wikipedia.org/wiki/Expected_value) | \mu |
| [**Mode**](http://en.wikipedia.org/wiki/Mode_%28statistics%29) | \mu\left[\left(1+\frac{9 \mu^2}{4 \lambda^2}\right)^\frac{1}{2}-\frac{3 \mu}{2 \lambda}\right] |
| [**Variance**](http://en.wikipedia.org/wiki/Variance) | \frac{\mu^3}{\lambda} |
| [**Skewness**](http://en.wikipedia.org/wiki/Skewness) | 3\left(\frac{\mu}{\lambda}\right)^{1/2} |
| [**Ex. kurtosis**](http://en.wikipedia.org/wiki/Excess_kurtosis) | \frac{15 \mu}{\lambda} |
| [**MGF**](http://en.wikipedia.org/wiki/Moment-generating_function) | e^{\left(\frac{\lambda}{\mu}\right)\left[1-\sqrt{1-\frac{2\mu^2t}{\lambda}}\right]} |
| [**CF**](http://en.wikipedia.org/wiki/Characteristic_function_%28probability_theory%29) | e^{\left(\frac{\lambda}{\mu}\right)\left[1-\sqrt{1-\frac{2\mu^2\mathrm{i}t}{\lambda}}\right]} |

In [probability theory](http://en.wikipedia.org/wiki/Probability_theory), the **inverse Gaussian distribution** (also known as the **Wald distribution**) is a two-parameter family of [continuous probability distributions](http://en.wikipedia.org/wiki/Continuous_probability_distribution) with [support](http://en.wikipedia.org/wiki/Support_%28mathematics%29) on (0,∞).

Its [probability density function](http://en.wikipedia.org/wiki/Probability_density_function) is given by

 f(x;\mu,\lambda)
= \left[\frac{\lambda}{2 \pi x^3}\right]^{1/2} \exp{\frac{-\lambda (x-\mu)^2}{2 \mu^2 x}}

for *x* > 0, where \mu > 0is the mean and \lambda > 0is the shape parameter.

As λ tends to infinity, the inverse Gaussian distribution becomes more like a [normal (Gaussian) distribution](http://en.wikipedia.org/wiki/Normal_distribution). The inverse Gaussian distribution has several properties analogous to a Gaussian distribution. The name can be misleading: it is an "inverse" only in that, while the Gaussian describes a [Brownian Motion's](http://en.wikipedia.org/wiki/Wiener_process) level at a fixed time, the inverse Gaussian describes the distribution of the time a Brownian Motion with positive drift takes to reach a fixed positive level.

Its cumulant generating function (logarithm of the characteristic function) is the inverse of the cumulant generating function of a Gaussian random variable.

To indicate that a [random variable](http://en.wikipedia.org/wiki/Random_variable) *X* is inverse Gaussian-distributed with mean μ and shape parameter λ we write

X \sim IG(\mu, \lambda).\,\!

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**Properties**

**Summation**

If *Xi* has a IG(*μ*0*wi*, *λ*0*wi*2) distribution for *i* = 1, 2, ..., *n* and all *Xi* are [independent](http://en.wikipedia.org/wiki/Statistical_independence), then


S=\sum_{i=1}^n X_i
\sim
IG \left(  \mu_0 \sum w_i, \lambda_0 \left(\sum w_i \right)^2  \right). 

Note that


\frac{\textrm{Var}(X_i)}{\textrm{E}(X_i)}= \frac{\mu_0^2 w_i^2 }{\lambda_0 w_i^2 }=\frac{\mu_0^2}{\lambda_0}


is constant for all *i*. This is a [necessary condition](http://en.wikipedia.org/wiki/Necessary_and_sufficient_conditions) for the summation. Otherwise *S* would not be inverse Gaussian.

**Scaling**

For any *t* > 0 it holds that


X \sim IG(\mu,\lambda) \,\,\,\,\,\, \Rightarrow \,\,\,\,\,\, tX \sim IG(t\mu,t\lambda).


**Exponential family**

The inverse Gaussian distribution is a two-parameter [exponential family](http://en.wikipedia.org/wiki/Exponential_family) with [natural parameters](http://en.wikipedia.org/wiki/Natural_parameters) -λ/(2μ²) and -λ/2, and [natural statistics](http://en.wikipedia.org/wiki/Natural_statistics) *X* and *1/X*.

**Differential equation**

Main article: [Differential equation](http://en.wikipedia.org/wiki/Differential_equation)


\left\{2 \mu ^2 x^2 f'(x)+f(x) \left(-\lambda  \mu ^2+\lambda  x^2+3 \mu
   ^2 x\right)=0,f(1)=\frac{\sqrt{\lambda } e^{-\frac{\lambda  (1-\mu
   )^2}{2 \mu ^2}}}{\sqrt{2 \pi }}\right\}


**Relationship with Brownian motion**

The [stochastic process](http://en.wikipedia.org/wiki/Stochastic_process) *Xt* given by

X_0 = 0\quad

X_t = \nu t + \sigma W_t\quad\quad\quad\quad

(where *Wt* is a standard [Brownian motion](http://en.wikipedia.org/wiki/Wiener_process) and \nu > 0) is a Brownian motion with drift *ν*.

Then, the [first passage time](http://en.wikipedia.org/wiki/First_passage_time) for a fixed level \alpha > 0by *Xt* is distributed according to an inverse-gaussian:

T_\alpha = \inf\{ 0 < t \mid X_t=\alpha \} \sim IG(\tfrac\alpha\nu, \tfrac {\alpha^2} {\sigma^2}).\,

**When drift is zero**

A common special case of the above arises when the Brownian motion has no drift. In that case, parameter μ tends to infinity, and the first passage time for fixed level α has probability density function

 f \left( x; 0, \left(\frac{\alpha}{\sigma}\right)^2 \right)
= \frac{\alpha}{\sigma \sqrt{2 \pi x^3}} \exp\left(-\frac{\alpha^2 }{2 x \sigma^2}\right).

This is a [Lévy distribution](http://en.wikipedia.org/wiki/L%C3%A9vy_distribution) with parameters c=\frac{\alpha^2}{\sigma^2}and \mu=0.

**Maximum likelihood**

The model where


X_i \sim IG(\mu,\lambda w_i), \,\,\,\,\,\, i=1,2,\ldots,n 


with all *wi* known, (*μ*, *λ*) unknown and all *Xi* [independent](http://en.wikipedia.org/wiki/Statistical_independence) has the following likelihood function


L(\mu, \lambda)=
\left(      \frac{\lambda}{2\pi}   \right)^\frac n 2  
\left(      \prod^n_{i=1} \frac{w_i}{X_i^3}    \right)^{\frac{1}{2}} 
\exp\left(\frac{\lambda}{\mu}\sum_{i=1}^n w_i -\frac{\lambda}{2\mu^2}\sum_{i=1}^n w_i X_i - \frac\lambda 2 \sum_{i=1}^n w_i \frac1{X_i} \right).


Solving the likelihood equation yields the following maximum likelihood estimates


\hat{\mu}= \frac{\sum_{i=1}^n w_i X_i}{\sum_{i=1}^n w_i}, \,\,\,\,\,\,\,\, \frac{1}{\hat{\lambda}}= \frac{1}{n} \sum_{i=1}^n w_i \left( \frac{1}{X_i}-\frac{1}{\hat{\mu}} \right).


\hat{\mu}and \hat{\lambda}are independent and


\hat{\mu} \sim IG \left(\mu, \lambda \sum_{i=1}^n w_i \right)  \,\,\,\,\,\,\,\, \frac{n}{\hat{\lambda}} \sim \frac{1}{\lambda} \chi^2_{n-1}.


**Generating random variates from an inverse-Gaussian distribution**

The following algorithm may be used.[[1]](http://en.wikipedia.org/wiki/Inverse_Gaussian_distribution#cite_note-1)

Generate a random variate from a normal distribution with a mean of 0 and 1 standard deviation


\displaystyle \nu = N(0,1).


Square the value

![
\displaystyle y = \nu^2
](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAADYAAAAWBAMAAAB5x3LYAAAAMFBMVEX///8EBAQiIiIWFhbm5uYMDAyenp6KiopQUFB0dHRAQEC2trYwMDBiYmLMzMwAAACBKDySAAAAAXRSTlMAQObYZgAAANFJREFUKBVjYMAB9t7ZgEOGgeUCtwguOe4PDN9wyTFsYPmHU46BqwG33CzcUmwXWHBK7vWbjUuO7///Dwx8QD+uRFHBpp/AwPoAJMTBtYDhO5DmMgYBI5DQfgaGQhDNkM16gfsLmAUnLjMwWEA47x/wBsCFwQwNBpjqywxMC1DlxBlYCyAiFgz8IBbCPr4vDCugisUZ9jtAmRCKM4DrAlTAnOEoihQDz7plMIE9d61gTAjNiuzd36hyCB5TA68BgofKYn6w1QFVBMFjv9GC4KCyABwfLaa7CFERAAAAAElFTkSuQmCC)

and use this relation


x = \mu + \frac{\mu^2 y}{2\lambda} - \frac{\mu}{2\lambda}\sqrt{4\mu \lambda y + \mu^2 y^2}.


Generate another random variate, this time sampled from a uniform distribution between 0 and 1


\displaystyle z = U(0,1).


If


z \le \frac{\mu}{\mu+x}


then return

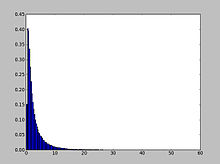
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else return

![
\frac{\mu^2}{x}.
](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAABoAAAArBAMAAACUQoX1AAAAMFBMVEX////MzMwwMDBQUFB0dHSenp4MDAxiYmIWFha2trZAQEDm5uYEBAQiIiKKiooAAADoe+fAAAAAAXRSTlMAQObYZgAAAMpJREFUKBVjYAADznJNCANMbmeYswHBnc/AH4DgcTLsF0DwGBgWI3NYFiDzwhkgpvBdYODZwFktMgEsybuA4T2D/P//EJX8DxjWIvTM38DQjuCVMXD/RPBuMbB+QPC+M3A1OMC4nJ8ZZiwogPHYk0oC1QVgPKB1SABoHRIAWocEHiGxyWf+hwOyzeBOQdbKfQSZRypbpIrdCa6H24H39nu4n9kZOAwYEXIosczAEA+XATEskHiMDF0M++D8eMlmBnjQM0i57HKBWgAAwmUyfEvfsh4AAAAASUVORK5CYII=)

Sample code in [Java](http://en.wikipedia.org/wiki/Java_%28programming_language%29):

1. public double inverseGaussian(double mu, double lambda) {
2. Random rand = new Random();
3. double v = rand.nextGaussian();   // sample from a normal distribution with a mean of 0 and 1 standard deviation
4. double y = v\*v;
5. double x = mu + (mu\*mu\*y)/(2\*lambda) - (mu/(2\*lambda)) \* Math.sqrt(4\*mu\*lambda\*y + mu\*mu\*y\*y);
6. double test = rand.nextDouble();  // sample from a uniform distribution between 0 and 1
7. if (test <= (mu)/(mu + x))
8. return x;
9. else
10. return (mu\*mu)/x;
11. }

[](http://en.wikipedia.org/wiki/File:Wald_Distribution_matplotlib.jpg)

[http://bits.wikimedia.org/static-1.24wmf8/skins/common/images/magnify-clip.png](http://en.wikipedia.org/wiki/File:Wald_Distribution_matplotlib.jpg)

Wald Distribution using Python with aid of matplotlib and NumPy

And to plot Wald distribution in [Python](http://en.wikipedia.org/wiki/Python_%28programming_language%29) using [matplotlib](http://en.wikipedia.org/wiki/Matplotlib) and [NumPy](http://en.wikipedia.org/wiki/Numpy):

1. import matplotlib.pyplot as plt
2. import numpy as np
4. h = plt.hist(np.random.wald(3, 2, 100000), bins=200, normed=True)
6. plt.show()

**Related distributions**

* If  X \sim \textrm{IG}(\mu,\lambda)\,then  k X \sim \textrm{IG}(k \mu,k \lambda)\,
* If  X_i \sim \textrm{IG}(\mu,\lambda)\,then  \sum_{i=1}^{n} X_i \sim \textrm{IG}(n \mu,n^2 \lambda)\,
* If  X_i \sim \textrm{IG}(\mu,\lambda)\,for i=1,\ldots,n\,then  \bar{X} \sim \textrm{IG}(\mu,n \lambda)\,
* If  X_i \sim \textrm{IG}(\mu_i,2 \mu^2_i)\,then  \sum_{i=1}^{n} X_i \sim \textrm{IG}\left(\sum_{i=1}^n \mu_i, 2 {\left( \sum_{i=1}^{n} \mu_i \right)}^2\right)\,

The convolution of a Wald distribution and an exponential (the ex-Wald distribution) is used as a model for response times in psychology.[[2]](http://en.wikipedia.org/wiki/Inverse_Gaussian_distribution#cite_note-Schwarz2001-2)

**History**

This distribution appears to have been first derived by Schrödinger in 1915 as the time to first passage of a Brownian motion.[[3]](http://en.wikipedia.org/wiki/Inverse_Gaussian_distribution#cite_note-Schrodinger1915-3) The name inverse Gaussian was proposed by Tweedie in 1945.[[4]](http://en.wikipedia.org/wiki/Inverse_Gaussian_distribution#cite_note-Folks1978-4) Wald re-derived this distribution in 1947 as the limiting form of a sample in a sequential probability ratio test. Tweedie investigated this distribution in 1957 and established some of its statistical properties.

**Software**

The R programming language has software for this distribution.[[5]](http://en.wikipedia.org/wiki/Inverse_Gaussian_distribution#cite_note-5)

**See also**

* [Generalized inverse Gaussian distribution](http://en.wikipedia.org/wiki/Generalized_inverse_Gaussian_distribution)
* [Tweedie distributions](http://en.wikipedia.org/wiki/Tweedie_distributions)—The inverse Gaussian distribution is a member of the family of Tweedie [exponential dispersion models](http://en.wikipedia.org/wiki/Exponential_dispersion_model)
* [Stopping time](http://en.wikipedia.org/wiki/Stopping_time)

**Notes**

* 1. Michael, John R.; Schucany, William R.; Haas, Roy W. (May 1976). "Generating Random Variates Using Transformations with Multiple Roots". *The American Statistician* ([American Statistical Association](http://en.wikipedia.org/wiki/American_Statistical_Association)) **30** (2): 88–90. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.2307/2683801](http://dx.doi.org/10.2307%2F2683801). [JSTOR](http://en.wikipedia.org/wiki/JSTOR) [2683801](http://www.jstor.org/stable/2683801). [edit](http://en.wikipedia.org/w/index.php?title=Template:Cite_doi/10.2307.2F2683801&action=edit&editintro=Template:Cite_doi/editintro2)
  2. Schwarz, W (2001). "The ex-Wald distribution as a descriptive model of response times". *Behavior research methods, instruments, & computers : a journal of the Psychonomic Society, Inc* **33** (4): 457–69. [PMID](http://en.wikipedia.org/wiki/PubMed_Identifier) [11816448](http://www.ncbi.nlm.nih.gov/pubmed/11816448). [edit](http://en.wikipedia.org/w/index.php?title=Template:Cite_pmid/11816448&action=edit&editintro=Template:Cite_pmid/editintro2)
  3. Schrodinger E (1915) Zur Theorie der Fall—und Steigversuche an Teilchenn mit Brownscher Bewegung. Physikalische Zeitschrift 16, 289-295
  4. Folks, J. L.; Chhikara, R. S. (1978). "The Inverse Gaussian Distribution and Its Statistical Application--A Review". *Journal of the Royal Statistical Society*. Series B (Methodological) **40** (3): 263–289. [doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.2307/2984691](http://dx.doi.org/10.2307%2F2984691). [JSTOR](http://en.wikipedia.org/wiki/JSTOR) [2984691](http://www.jstor.org/stable/2984691). [edit](http://en.wikipedia.org/w/index.php?title=Template:Cite_doi/10.2307.2F2984691&action=edit&editintro=Template:Cite_doi/editintro2)
  5. Giner, Goknur. ["A monotonically convergent Newton iteration for the quantiles of any unimodal distribution, with application to the inverse Gaussian distribution"](http://www.statsci.org/smyth/pubs/qinvgaussPreprint.pdf).

**References**

* *The inverse gaussian distribution: theory, methodology, and applications* by Raj Chhikara and Leroy Folks, 1989 [ISBN 0-8247-7997-5](http://en.wikipedia.org/wiki/Special:BookSources/0824779975)
* *System Reliability Theory* by Marvin Rausand and [Arnljot Høyland](http://en.wikipedia.org/wiki/Arnljot_H%C3%B8yland)
* *The Inverse Gaussian Distribution* by Dr. V. Seshadri, Oxford Univ Press, 1993

**External links**

* [Inverse Gaussian Distribution](http://mathworld.wolfram.com/InverseGaussianDistribution.html) in Wolfram website.

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