

Chapter 4: Random Variables and Distributions

Ott & Longnecker Sections: 4.6-4.10

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Part 3



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What do we study?



We'll continue RV.



What do we study?



Key Concepts: normal distribution, standard normal distribution, z critical values, standardization, reverse standardization, Z table.

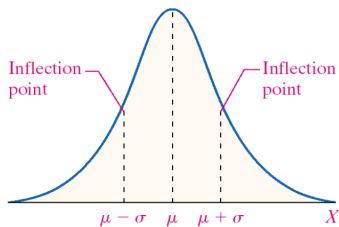
- 1 Continuous RV
- 2 The bell curve
- 3 Normal distribution
- 4 Standard normal distribution
- 5 Z table
- 6 Standardization
- 7 Reverse standardization and z critical value



We now discuss continuous RVs. Recall that continuous RVs take values in specified ranges, and their probability distributions are called **probability density functions**, or pdfs, which are denoted $f(x)$. The area under the curve described by the pdf between any two possible realizations of the RV determines the probability that the RV will realize to a value in that range.

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The bell curve



It's a special curve, called a **normal**, **Gaussian**, or **bell** curve. If the pdf of X is a bell curve, then we say X has the normal distribution. Lots of biological (and other) random variables are normal, for example, body weight, crop yield, protein content in soybean, density of blood components.



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If X is a normal RV, then the pdf is

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

- $\mu = E(X)$, $\sigma^2 = \text{VAR}(X)$. We often denote a normal RV X with mean μ and variance σ^2 by $X \sim N(\mu, \sigma^2)$.
- Don't confuse this π , which is the fundamental math constant that is approximately 3.14, with the π that represents the chance of success in a Bernoulli trial!

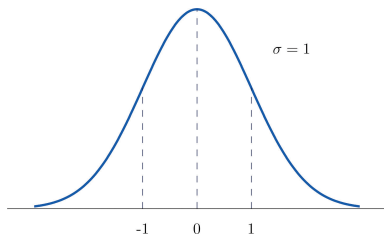
You can play with the bell curve at
<https://dzwang.shinyapps.io/thebellcurve/>

- 1 A normal RV can theoretically realize to any value between $-\infty$ and ∞ .
- 2 The normal distribution is symmetric around the mean, μ .
- 3 The inflection points (points where the curve moves from concave downward to concave upward) are at $\mu \pm \sigma$.
- 4 The total area under the curve is 1.
- 5 The area under the curve between $\mu - \sigma$ and $\mu + \sigma$ is about 0.68; the area under the curve between $\mu - 2\sigma$ and $\mu + 2\sigma$ is about 0.95. Very little of the area is farther than three sds from the mean (about 0.003).



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The standard normal distribution



We call the $N(0, 1)$ distribution the **standard normal distribution** and we usually reserve Z to denote a standard normal RV.

- $P(Z \leq 0) = ?$
- $P(Z = 0) = ?$
- $P(Z < 1) = ?$
- $P(0 \leq Z \leq 1) = ?$
- $P(-1 \leq Z \leq 1) = ?$
- $P(Z > 1.5) = ?$

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$$P(Z \leq 0) = \frac{1}{2} \text{ (by symmetry)}$$

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But how do we calculate others?

Two tools



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
-3.9	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.8	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.7	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.6	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.5	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.4	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.3	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.2	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.1	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
-3.0	.0010	.0009	.0008	.0007	.0006	.0005	.0004	.0003	.0002	.0001
-2.9	.0011	.0010	.0009	.0008	.0007	.0006	.0005	.0004	.0003	.0002
-2.8	.0013	.0012	.0011	.0010	.0009	.0008	.0007	.0006	.0005	.0004
-2.7	.0016	.0015	.0014	.0013	.0012	.0011	.0010	.0009	.0008	.0007
-2.6	.0019	.0018	.0017	.0016	.0015	.0014	.0013	.0012	.0011	.0010
-2.5	.0024	.0023	.0022	.0021	.0020	.0019	.0018	.0017	.0016	.0015
-2.4	.0029	.0028	.0027	.0026	.0025	.0024	.0023	.0022	.0021	.0020
-2.3	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026	.0025
-2.2	.0040	.0039	.0038	.0037	.0036	.0035	.0034	.0033	.0032	.0031
-2.1	.0046	.0045	.0044	.0043	.0042	.0041	.0040	.0039	.0038	.0037
-2.0	.0054	.0053	.0052	.0051	.0050	.0049	.0048	.0047	.0046	.0045
-1.9	.0062	.0061	.0060	.0059	.0058	.0057	.0056	.0055	.0054	.0053
-1.8	.0071	.0070	.0069	.0068	.0067	.0066	.0065	.0064	.0063	.0062
-1.7	.0080	.0079	.0078	.0077	.0076	.0075	.0074	.0073	.0072	.0071
-1.6	.0090	.0089	.0088	.0087	.0086	.0085	.0084	.0083	.0082	.0081
-1.5	.0100	.0099	.0098	.0097	.0096	.0095	.0094	.0093	.0092	.0091
-1.4	.0109	.0108	.0107	.0106	.0105	.0104	.0103	.0102	.0101	.0100
-1.3	.0119	.0118	.0117	.0116	.0115	.0114	.0113	.0112	.0111	.0110
-1.2	.0129	.0128	.0127	.0126	.0125	.0124	.0123	.0122	.0121	.0120
-1.1	.0148	.0147	.0146	.0145	.0144	.0143	.0142	.0141	.0140	.0139
-1.0	.0169	.0168	.0167	.0166	.0165	.0164	.0163	.0162	.0161	.0160
-0.9	.0190	.0189	.0188	.0187	.0186	.0185	.0184	.0183	.0182	.0181
-0.8	.0212	.0211	.0210	.0209	.0208	.0207	.0206	.0205	.0204	.0203
-0.7	.0233	.0232	.0231	.0230	.0229	.0228	.0227	.0226	.0225	.0224
-0.6	.0255	.0254	.0253	.0252	.0251	.0250	.0249	.0248	.0247	.0246
-0.5	.0276	.0275	.0274	.0273	.0272	.0271	.0270	.0269	.0268	.0267
-0.4	.0297	.0296	.0295	.0294	.0293	.0292	.0291	.0290	.0289	.0288
-0.3	.0318	.0317	.0316	.0315	.0314	.0313	.0312	.0311	.0310	.0309
-0.2	.0339	.0338	.0337	.0336	.0335	.0334	.0333	.0332	.0331	.0330
-0.1	.0359	.0358	.0357	.0356	.0355	.0354	.0353	.0352	.0351	.0350
0.0	.0379	.0378	.0377	.0376	.0375	.0374	.0373	.0372	.0371	.0370
0.1	.0398	.0397	.0396	.0395	.0394	.0393	.0392	.0391	.0390	.0389
0.2	.0418	.0417	.0416	.0415	.0414	.0413	.0412	.0411	.0410	.0409
0.3	.0438	.0437	.0436	.0435	.0434	.0433	.0432	.0431	.0430	.0429
0.4	.0458	.0457	.0456	.0455	.0454	.0453	.0452	.0451	.0450	.0449
0.5	.0478	.0477	.0476	.0475	.0474	.0473	.0472	.0471	.0470	.0469
0.6	.0498	.0497	.0496	.0495	.0494	.0493	.0492	.0491	.0490	.0489
0.7	.0518	.0517	.0516	.0515	.0514	.0513	.0512	.0511	.0510	.0509
0.8	.0538	.0537	.0536	.0535	.0534	.0533	.0532	.0531	.0530	.0529
0.9	.0558	.0557	.0556	.0555	.0554	.0553	.0552	.0551	.0550	.0549
1.0	.0578	.0577	.0576	.0575	.0574	.0573	.0572	.0571	.0570	.0569
1.1	.0598	.0597	.0596	.0595	.0594	.0593	.0592	.0591	.0590	.0589
1.2	.0618	.0617	.0616	.0615	.0614	.0613	.0612	.0611	.0610	.0609
1.3	.0638	.0637	.0636	.0635	.0634	.0633	.0632	.0631	.0630	.0629
1.4	.0658	.0657	.0656	.0655	.0654	.0653	.0652	.0651	.0650	.0649
1.5	.0678	.0677	.0676	.0675	.0674	.0673	.0672	.0671	.0670	.0669
1.6	.0698	.0697	.0696	.0695	.0694	.0693	.0692	.0691	.0690	.0689
1.7	.0718	.0717	.0716	.0715	.0714	.0713	.0712	.0711	.0710	.0709
1.8	.0738	.0737	.0736	.0735	.0734	.0733	.0732	.0731	.0730	.0729
1.9	.0758	.0757	.0756	.0755	.0754	.0753	.0752	.0751	.0750	.0749
2.0	.0778	.0777	.0776	.0775	.0774	.0773	.0772	.0771	.0770	.0769
2.1	.0798	.0797	.0796	.0795	.0794	.0793	.0792	.0791	.0790	.0789
2.2	.0818	.0817	.0816	.0815	.0814	.0813	.0812	.0811	.0810	.0809
2.3	.0838	.0837	.0836	.0835	.0834	.0833	.0832	.0831	.0830	.0829
2.4	.0858	.0857	.0856	.0855	.0854	.0853	.0852	.0851	.0850	.0849
2.5	.0878	.0877	.0876	.0875	.0874	.0873	.0872	.0871	.0870	.0869
2.6	.0898	.0897	.0896	.0895	.0894	.0893	.0892	.0891	.0890	.0889
2.7	.0918	.0917	.0916	.0915	.0914	.0913	.0912	.0911	.0910	.0909
2.8	.0938	.0937	.0936	.0935	.0934	.0933	.0932	.0931	.0930	.0929
2.9	.0958	.0957	.0956	.0955	.0954	.0953	.0952	.0951	.0950	.0949
3.0	.0978	.0977	.0976	.0975	.0974	.0973	.0972	.0971	.0970	.0969



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Standard Normal Probabilities

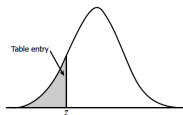


Table entry for z is the area under the standard normal curve to the left of z .

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
-3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
-3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
-3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
-3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
-3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
-2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
-2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
-1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
-1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
-1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
-1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
-0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
-0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
-0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148

Standard Normal Probabilities

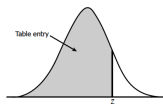


Table entry for z is the area under the standard normal curve to the left of z .

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441

$$P(Z < 1) = ?$$

Standard Normal Probabilities

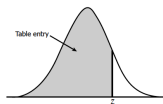


Table entry for z is the area under the standard normal curve to the left of z .

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441

$$P(Z < 1) = ?$$

$$0.8413$$

$$P(0 \leq Z \leq 1) = ?$$

$$P(0 \leq Z \leq 1) = ?$$

$$P(0 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq 0) = 0.8413 - 0.5 = 0.3413$$

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$$P(-1 \leq Z \leq 1) = ?$$

$$P(0 \leq Z \leq 1) = ?$$

$$P(0 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq 0) = 0.8413 - 0.5 = 0.3413$$

$$P(-1 \leq Z \leq 1) = ?$$

$$P(-1 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq -1) = 0.8413 - 0.1587 = 0.6826$$

$$P(0 \leq Z \leq 1) = ?$$

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$$P(-1 \leq Z \leq 1) = ?$$

$$P(-1 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq -1) = 0.8413 - 0.1587 = 0.6826$$

$$P(Z > 1.5) = ?$$

$$P(0 \leq Z \leq 1) = ?$$

$$P(0 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq 0) = 0.8413 - 0.5 = 0.3413$$

$$P(-1 \leq Z \leq 1) = ?$$

$$P(-1 \leq Z \leq 1) = P(Z \leq 1) - P(Z \leq -1) = 0.8413 - 0.1587 = 0.6826$$

$$P(Z > 1.5) = ?$$

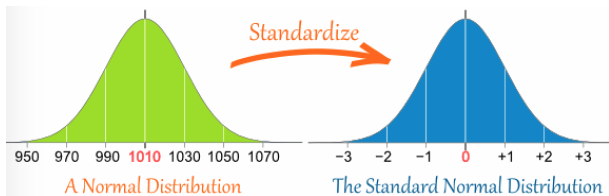
$$P(Z > 1.5) = 1 - P(Z \leq 1.5) = 1 - 0.9332 = 0.0668$$

Example. $Y \sim N(3, 0.25^2)$, how do we calculate $P(Y \leq 2.8)$?

But what if...



Example. $Y \sim N(3, 0.25^2)$, how do we calculate $P(Y \leq 2.8)$?



- 1 Continuous RV
- 2 The bell curve
- 3 Normal distribution
- 4 Standard normal distribution
- 5 Z table
- 6 Standardization**
- 7 Reverse standardization and z critical value



If $X \sim N(\mu, \sigma^2)$, then $Z = \frac{X - \mu}{\sigma} \sim N(0, 1)$.

Note: this is a very **important** technique, we'll use this fact a lot of times in this course.



Example. $Y \sim N(3, 0.25^2)$, how do we calculate $P(Y \leq 2.8)$?

Example. $Y \sim N(3, 0.25^2)$, how do we calculate $P(Y \leq 2.8)$?

$$P(Y \leq 2.8) = P\left(\frac{Y-3}{0.25} \leq \frac{2.8-3}{0.25}\right),$$

then we have

$$P(Y \leq 2.8) = P(Z \leq -0.8).$$

We can use the Z table to compute $P(Z \leq -0.8)$, and we get 0.21.

Example. $Y \sim N(3, 0.25^2)$, how do we **find y** such that

$$P(Y \geq y) = 0.25$$

- 1 Continuous RV
- 2 The bell curve
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If $Z \sim N(0, 1)$, then $X = Z\sigma + \mu \sim N(\mu, \sigma^2)$.

Note: this is also a very **important** technique.



Let $Z \sim N(0, 1)$, α is given, then the value z such that $P(Z \geq z) = \alpha$ is called z_α . We call z_α a *z critical value*. It can be thought of as the $1 - \alpha$ quantile of the standard normal distribution (recall the definition of quantile from the section on descriptive statistics!).

Example. $Y \sim N(3, 0.25^2)$, how do we **find** **y** such that

$$P(Y \geq y) = 0.25$$

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step 1:

Find z such that $P(Z \geq z) = 0.25$,

Use Z table, we find the 0.25 critical value of the standard normal distribution to be $z_{0.25} = 0.67$.

Example. $Y \sim N(3, 0.25^2)$, how do we **find y** such that

$$P(Y \geq y) = 0.25$$

step 1:

Find z such that $P(Z \geq z) = 0.25$,

Use Z table, we find the 0.25 critical value of the standard normal distribution to be $z_{0.25} = 0.67$.

step 2:

Use reverse standardization to find the appropriate value of y

Reverse standardizing gives $0.25 * 0.67 + 3 = 3.17$.



You need to know how to use Z table to calculate probability and find the z critical value, particularly for exams. It's very **important**, so feel free to do many different examples until you feel confident and comfortable.

<pre>> pnorm(1) [1] 0.8413447 > pnorm(2)-pnorm(-2) [1] 0.9544997 > pnorm(3)-pnorm(-3) [1] 0.9973002 > 1- pnorm(137, mean=112, sd=10) [1] 0.006209665 > qnorm(.95, mean=112, sd=10) [1] 128.4485 > pbinom(1, size=6, prob=1/6) [1] 0.7367755 > dbinom(0:6, size=6, prob=1/6) [1] 0.335 0.402 0.201 0.054 0.008 0.001 0.000</pre>	<table border="0"><tr><td>norm</td><td>normal distribution</td></tr><tr><td>binom</td><td>binomial</td></tr><tr><td>p</td><td>probability: $\mathbb{P}\{Y \leq \dots\}$</td></tr><tr><td>q</td><td>quantile</td></tr><tr><td>d</td><td>density, or probability mass function: $\mathbb{P}\{Y = \dots\}$</td></tr></table>	norm	normal distribution	binom	binomial	p	probability: $\mathbb{P}\{Y \leq \dots\}$	q	quantile	d	density, or probability mass function: $\mathbb{P}\{Y = \dots\}$
norm	normal distribution										
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What's the next?



In the next lecture, we'll discuss the distributions of functions of RVs and concepts of estimation.