

Proposed in 2014

#### Going deeper with convolutions

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#### Abstract

We propose a deep convolutional neural network architecture codenamed Inception, which was responsible for setting the new state of the art for classification and detection in the ImageNet Large-Scale Visual Recognition Challenge 2014 (ILSVRC14). The main hallmark of this architecture is the improved utilization of the computing resources inside the network. This was achieved by a carefully crafted design that allows for increasing the depth and width of the network while keeping the computational budget constant. To optimize quality, the architectural decisions were based on the Hebbian principle and the intuition of multi-scale processing. One particular incarnation used in our submission for ILSVRC14 is called GoogLeNet, a 22 layers deep network, the quality of which is assessed in the context of classification and detection.



- Proposed in 2014
- It has 22 layers with learnable parameters





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- Architecture details: Analytics
  - 2 initial convolution layers with max pooling



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  - 2 fully connected layers



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- It has 22 layers with learnable parameters
- - 2 initial convolution layers with max pooling
  - 9 inception modules
  - 2 fully connected layers
- Trained on imagenet dataset



type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
convolution	7×7/2	112×112×64	1							2.7K	34M
max pool	3×3/2	56×56×64	0			-					
convolution	3×3/1	56×56×192	2		64	192				112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0			8					
dropout (40%)		1×1×1024	0						- 2		
linear		1×1×1000	1							1000K	1M
softmax		1×1×1000	0						, , , , , , , , , , , , , , , , , , ,		



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convolution	3×3/1	56×56×192	2		64	192				112K	360M





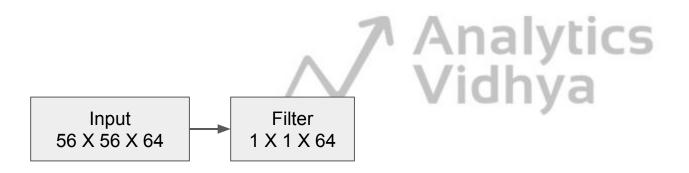
type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
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max pool	3×3/2	$56 \times 56 \times 64$	0								
convolution	3×3/1	$56 \times 56 \times 192$	2		64	192			X	112K	360M



Input 56 X 56 X 64

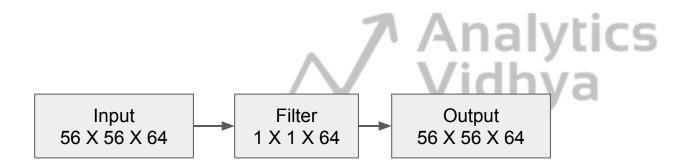


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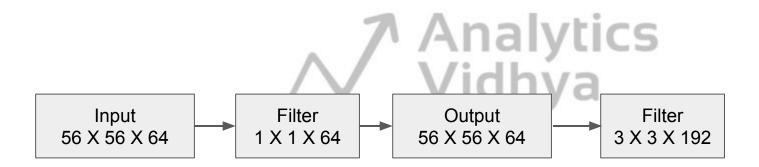


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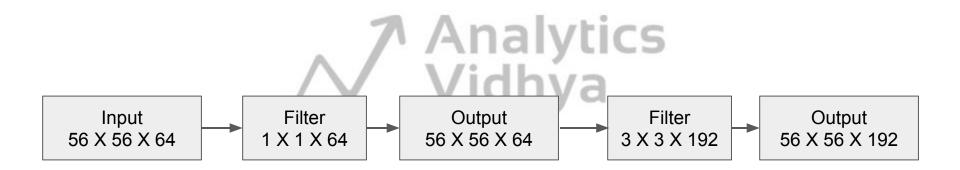


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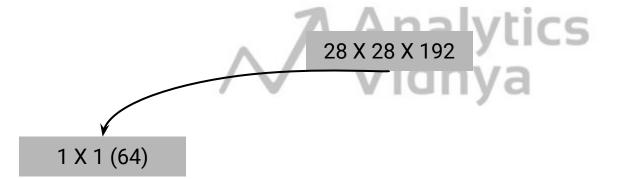


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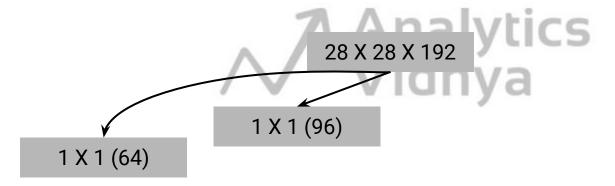


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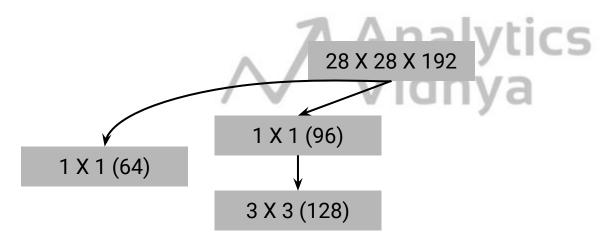


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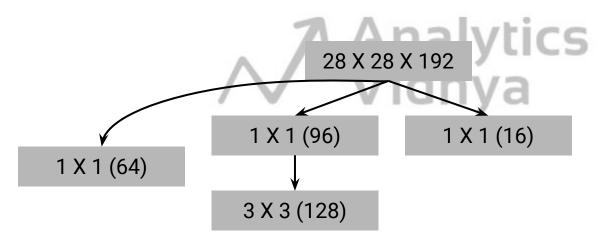


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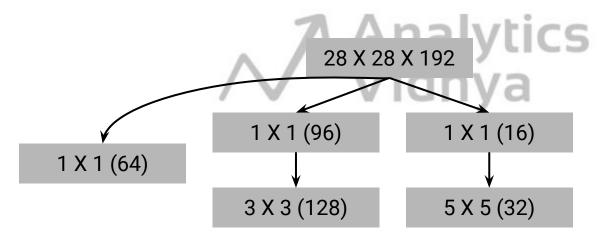


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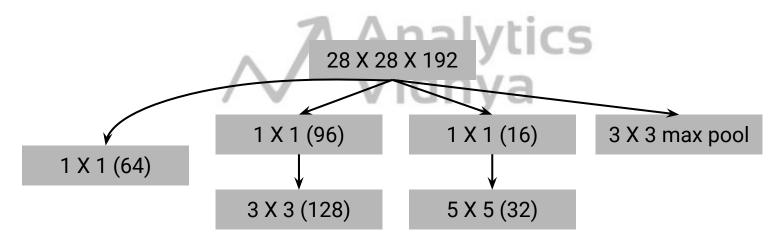


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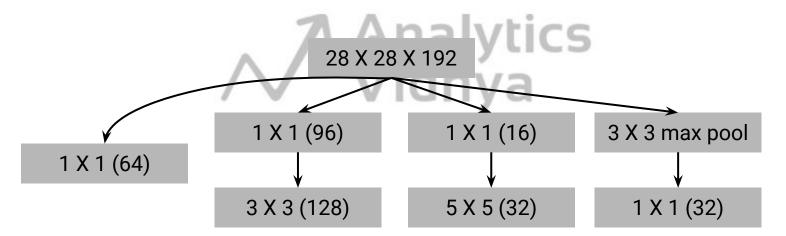


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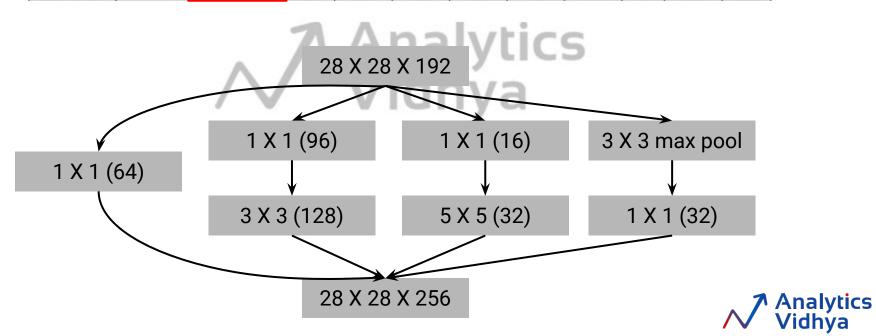


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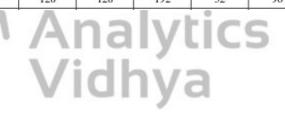




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inception (3a)		$28 \times 28 \times 256$	2	64	96	128	16	32	32	159K	128M



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max pool	3×3/2	56×56×64	0						2		
convolution	3×3/1	56×56×192	2		64	192			20	112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M



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3×3/2	56×56×64	0			-					
3×3/1	56×56×192	2		64	192				112K	360M
3×3/2	28×28×192	0								
	28×28×256	2	64	96	128	16	32	32	159K	128M
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	14×14×832	2	256	160	320	32	128	128	840K	170M
3×3/2	7×7×832	0								
	7×7/2 3×3/2 3×3/1 3×3/2 3×3/2	7×7/2 112×112×64 3×3/2 56×56×64 3×3/1 56×56×192 3×3/2 28×28×192 28×28×256 28×28×480 3×3/2 14×14×480 14×14×512 14×14×512 14×14×528 14×14×528	stride  size    7×7/2  112×112×64  1    3×3/2  56×56×64  0    3×3/1  56×56×192  2    3×3/2  28×28×192  0    28×28×256  2    28×28×480  2    3×3/2  14×14×480  0    14×14×512  2    14×14×512  2    14×14×512  2    14×14×528  2    14×14×832  2	stride  size    7×7/2  112×112×64  1    3×3/2  56×56×64  0    3×3/1  56×56×192  2    3×3/2  28×28×192  0    28×28×256  2  64    28×28×480  2  128    3×3/2  14×14×480  0    14×14×512  2  192    14×14×512  2  160    14×14×512  2  128    14×14×528  2  112    14×14×832  2  256	stride  size  reduce    7×7/2  112×112×64  1    3×3/2  56×56×64  0    3×3/1  56×56×192  2  64    3×3/2  28×28×192  0  64    28×28×256  2  64  96    28×28×480  2  128  128    3×3/2  14×14×480  0  192  96    14×14×512  2  160  112    14×14×512  2  128  128    14×14×528  2  112  144    14×14×832  2  256  160	stride  size  reduce    7×7/2  112×112×64  1    3×3/2  56×56×64  0    3×3/1  56×56×192  2  64  192    3×3/2  28×28×192  0  28×28×256  2  64  96  128    28×28×286  2  64  96  128  192    3×3/2  14×14×480  0  128  192    3×3/2  14×14×512  2  192  96  208    14×14×512  2  160  112  224    14×14×512  2  128  128  256    14×14×528  2  112  144  288    14×14×832  2  256  160  320	stride  size  reduce  reduce  reduce    7×7/2  112×112×64  1      3×3/2  56×56×64  0      3×3/1  56×56×192  2  64  192    3×3/2  28×28×192  0      28×28×256  2  64  96  128  16    28×28×480  2  128  128  192  32    3×3/2  14×14×480  0	stride  size  reduce  reduce    7×7/2  112×112×64  1  3×3/2  56×56×64  0    3×3/1  56×56×192  2  64  192    3×3/2  28×28×192  0  28×28×256  2  64  96  128  16  32    28×28×480  2  128  128  192  32  96    3×3/2  14×14×480  0  3  14×14×512  2  192  96  208  16  48    14×14×512  2  160  112  224  24  64    14×14×512  2  128  128  256  24  64    14×14×528  2  112  144  288  32  64    14×14×832  2  256  160  320  32  128	stride  size  reduce  reduce  reduce  proj    7×7/2  112×112×64  1	Stride   Size   Feduce   Fed



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inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0								



type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
convolution	7×7/2	112×112×64	1							2.7K	34M
max pool	3×3/2	56×56×64	0			-					
convolution	3×3/1	56×56×192	2		64	192				112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0								
dropout (40%)		1×1×1024	0								
linear		1×1×1000	1							1000K	1M
softmax		1×1×1000	0						7		



type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
convolution	7×7/2	112×112×64	1							2.7K	34M
max pool	3×3/2	56×56×64	0			-			2		
convolution	3×3/1	56×56×192	2		64	192			20	112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0								
dropout (40%)		1×1×1024	0						2	ĺ	
linear		1×1×1000	1							1000K	1M
softmax		1×1×1000	0						7		



# **Auxiliary Classifiers**

type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
convolution	7×7/2	112×112×64	1							2.7K	34M
max pool	3×3/2	56×56×64	0								
convolution	3×3/1	56×56×192	2		64	192				112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0								
dropout (40%)		1×1×1024	0								
linear		1×1×1000	1							1000K	1M
softmax		1×1×1000	0								



Average pooling: filter size - 5 X 5, stride - 3





- Average pooling: filter size 5 X 5, stride 3
- 1 X 1 convolution with 128 filters: dimensionality reduction + ReLU





- Average pooling: filter size 5 X 5, stride 3
- 1 X 1 convolution with 128 filters: dimensionality reduction + ReLU
- Fully connected layer with 1024 neurons + ReLU



- Average pooling: filter size 5 X 5, stride 3
- 1 X 1 convolution with 128 filters: dimensionality reduction + ReLU
- Fully connected layer with 1024 neurons + ReLU
- Dropout layer: dropout ratio 70%



- Average pooling: filter size 5 X 5, stride 3
- 1 X 1 convolution with 128 filters: dimensionality reduction + ReLU
- Fully connected layer with 1024 neurons + ReLU
- Dropout layer: dropout ratio 70%
- Fully connected layer with 1000 neurons + Softmax



- Average pooling: filter size 5 X 5, stride 3
- 1 X 1 convolution with 128 filters: dimensionality reduction + ReLU
- Fully connected layer with 1024 neurons + ReLU
- Dropout layer: dropout ratio 70%
- Fully connected layer with 1000 neurons + Softmax
- No auxiliary classifier at inference time









• It has 22 layers with learnable parameters





- It has 22 layers with learnable parameters
- Takes RGB image as input





Analytics

- It has 22 layers with learnable parameters
- Takes RGB image as input
- Architecture details:
  - 2 initial convolution layers with max pooling
  - 9 inception modules
  - 2 fully connected layers
  - 2 Auxiliary classifiers



Analytics

- It has 22 layers with learnable parameters
- Takes RGB image as input
- Architecture details:
  - 2 initial convolution layers with max pooling
  - 9 inception modules
  - 2 fully connected layers
  - 2 Auxiliary classifiers
- Total number of parameters: 6.8 million





