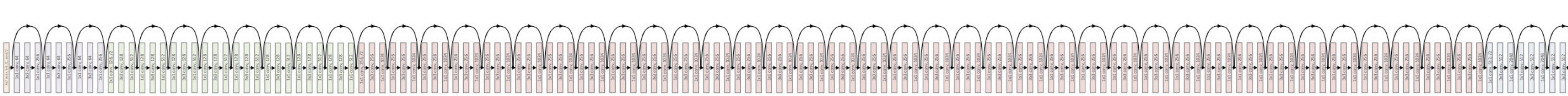
Deep Residual Learning for Image Recognition

"CVPR 2016 Best Paper Award"

Presenter : Jingyun Ning



Introduction

Deep Residual Networks (ResNets)

- A simple and clean framework of training “very” deep nets
- State-of-the-art performance for
  - Image classification
  - Object detection
  - Semantic segmentation
  - and more...

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. “Deep Residual Learning for Image Recognition”. arXiv 2015.

ResNets @ ILSVRC & COCO 2015 Competitions

- **1st places in all five main tracks**
  - ImageNet Classification: "*Ultra-deep*" 152-layer nets
  - ImageNet Detection: 16% better than 2nd
  - ImageNet Localization: 27% better than 2nd
  - COCO Detection: 11% better than 2nd
  - COCO Segmentation: 12% better than 2nd

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.

Result

- Performances increase absolutely

task	2nd-place winner	MSRA	margin (relative)
ImageNet Localization (top-5 error)	12.0	9.0	**27%**
ImageNet Detection (mAP@.5)	53.6	62.1	**16%**
COCO Detection (mAP@.5:.95)	33.5	37.3	**11%**
COCO Segmentation (mAP@.5:.95)	25.1	28.2	**12%**

absolute 8.5% better!

- Based on ResNet-101
- Existing techniques can use residual networks or features from it

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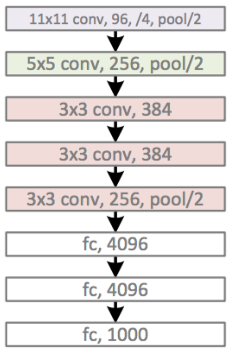
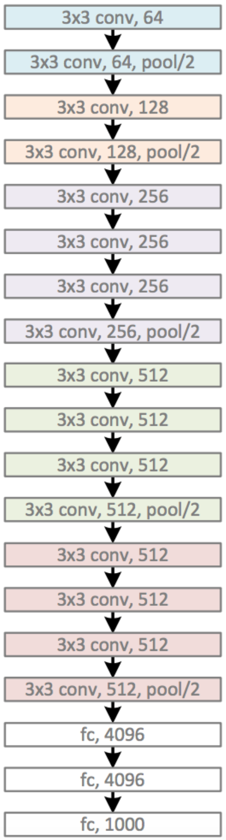
Revolution of Depth

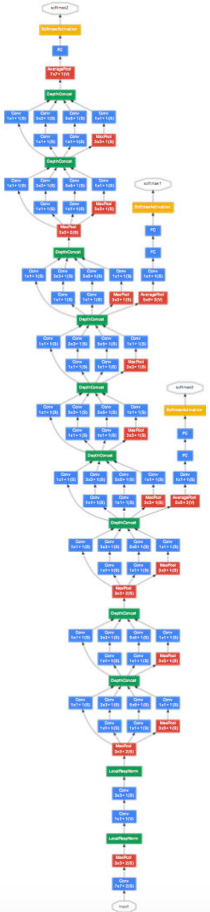
AlexNet, 8 layers
(ILSVRC 2012)



VGG, 19 layers
(ILSVRC 2014)



GoogleNet, 22 layers
(ILSVRC 2014)



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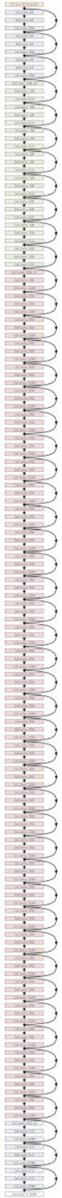
Revolution of Depth

AlexNet, 8 layers
(ILSVRC 2012)

VGG, 19 layers
(ILSVRC 2014)

ResNet, 152 layers
(ILSVRC 2015)



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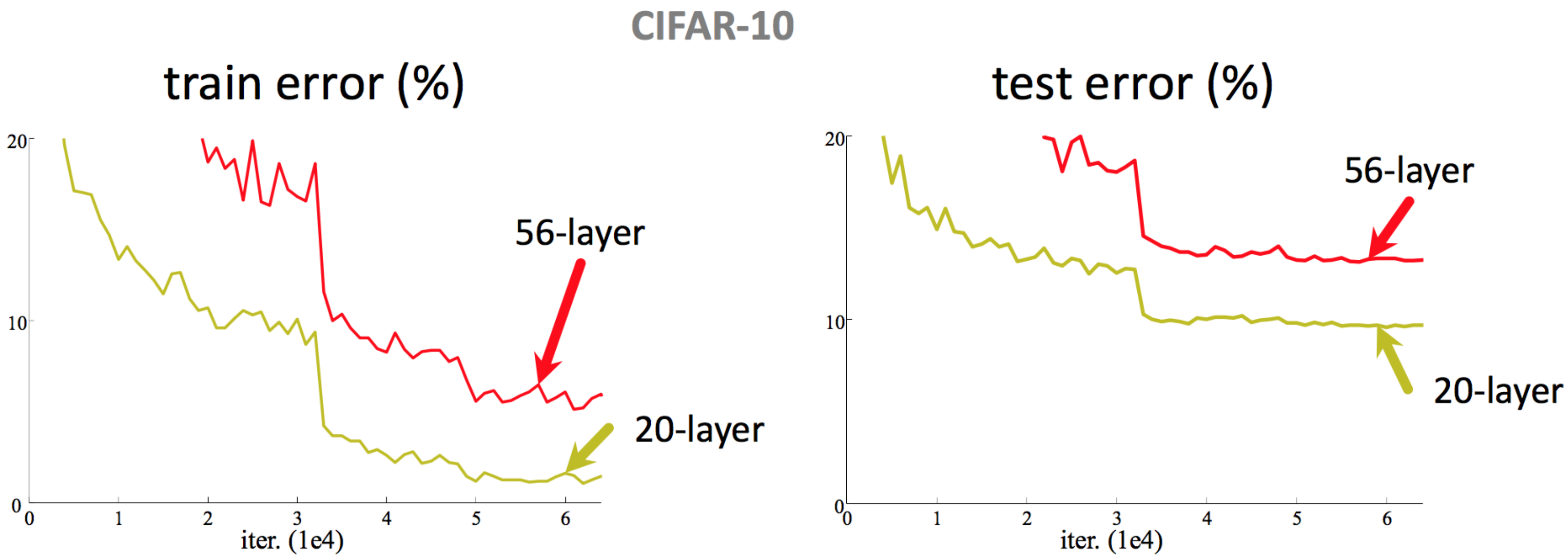
Is learning better networks as simple as s

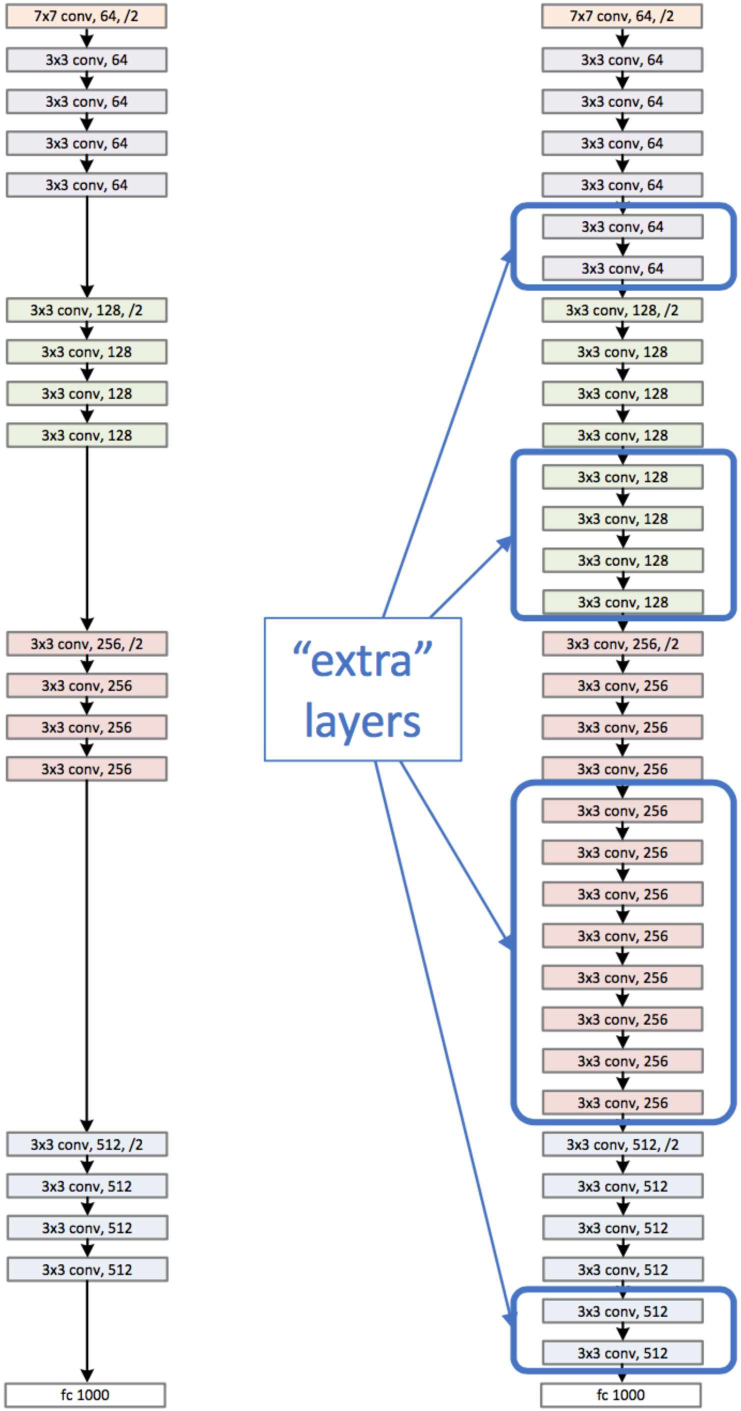
No!

Simply stacking layers?



- Plain nets: stacking 3x3 Convlayers...
- 56-layer net has higher training error and test error than 20-layer net

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.



Left : a shallower model (18 layers)
Right : a deeper counterpart (34 layers)

- A deeper model should not have **higher training error**
- A solution by construction:
  - original layers: copied from a learned shallower model
  - extra layers: set as **identity**
  - at least the same training error
- **Optimization difficulties**: solvers cannot find the solution when going deeper…

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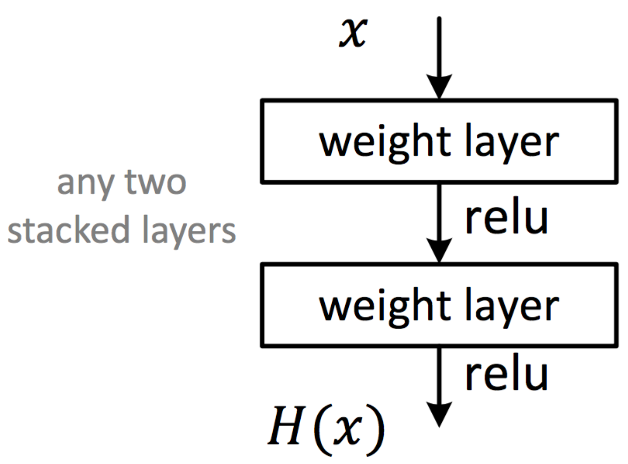
Deep Residual Learning

- Plaint net



$H(x)$ is any desired mapping, hope the 2 weight layers fit $H(x)$

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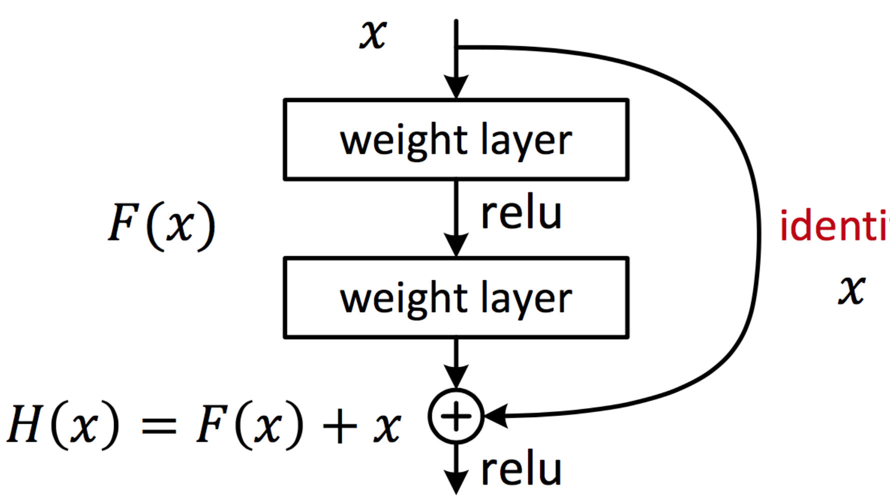
Deep Residual Learning

- Residual net



$H(x)$ is any desired mapping,

hope the 2 weight layers fit $H(x)$

hope the 2 weight layers fit $F(x)$

let $H(x) = F(x) + x$

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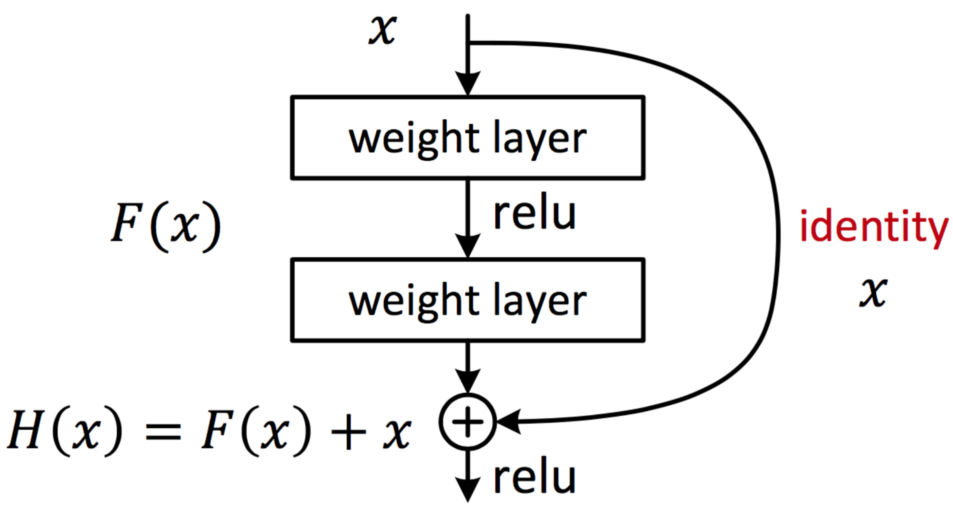
Deep Residual Learning

- F x is a residual mapping w.r.t. identity



- If identity were optimal, easy to set weights as 0
- If optimal mapping is closer to identity, easier to find small fluctuations

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.

Network "Design"

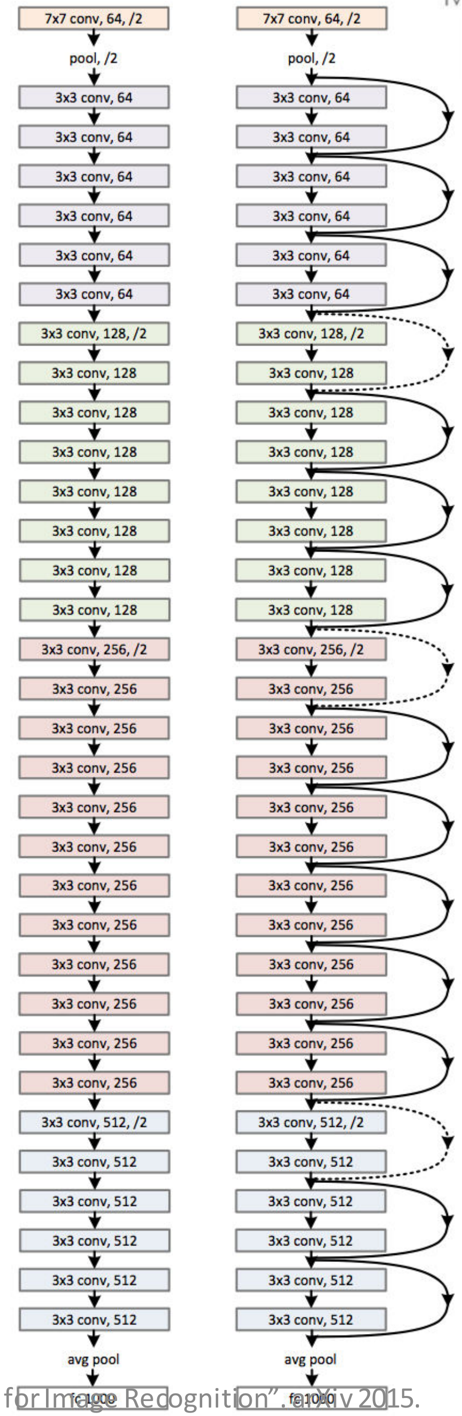
- Keep it simple

- The basic design (VGG-style)
  - all 3x3 conv (almost)
- spatial size /2 => # filters x2
  - Simple design; just deep!

Other remarks:

- no max pooling(almost)
- no hidden fc
- no dropout

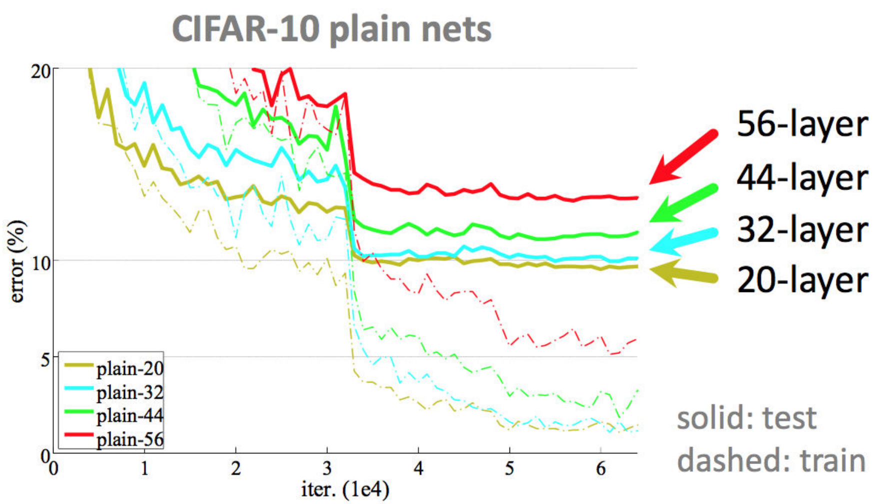
plain net

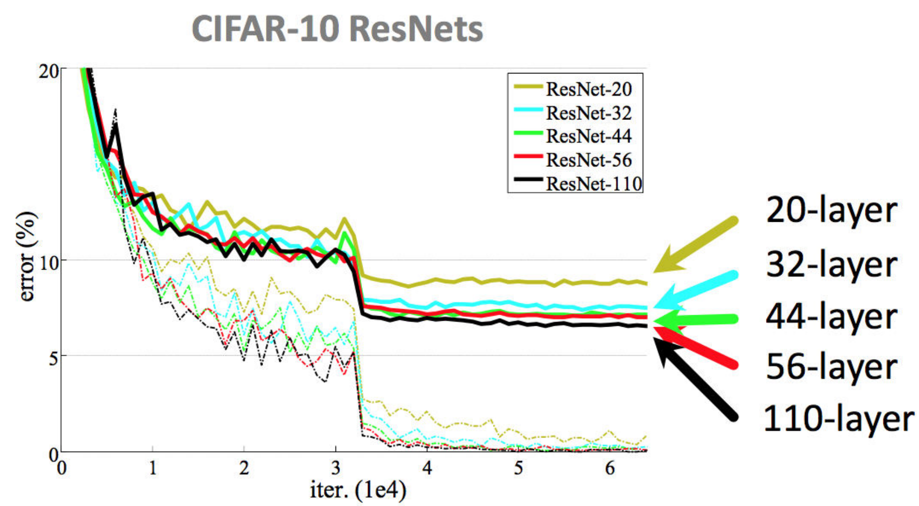


ResNet

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.

CIFAR-10 experiments

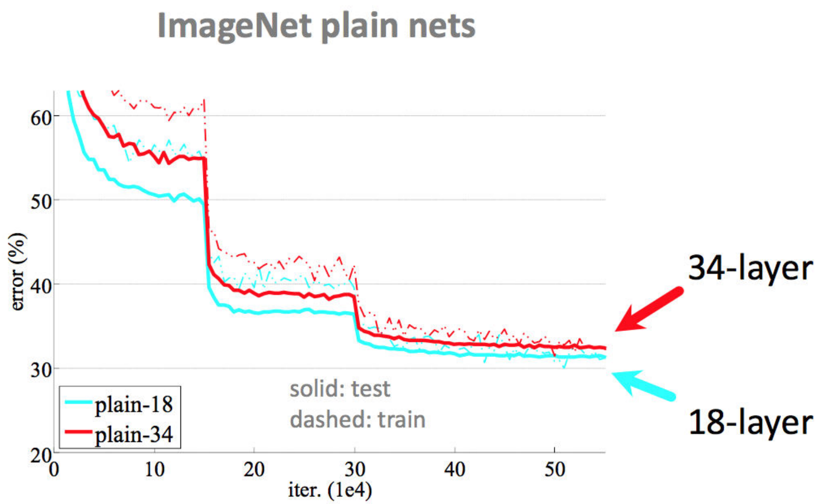


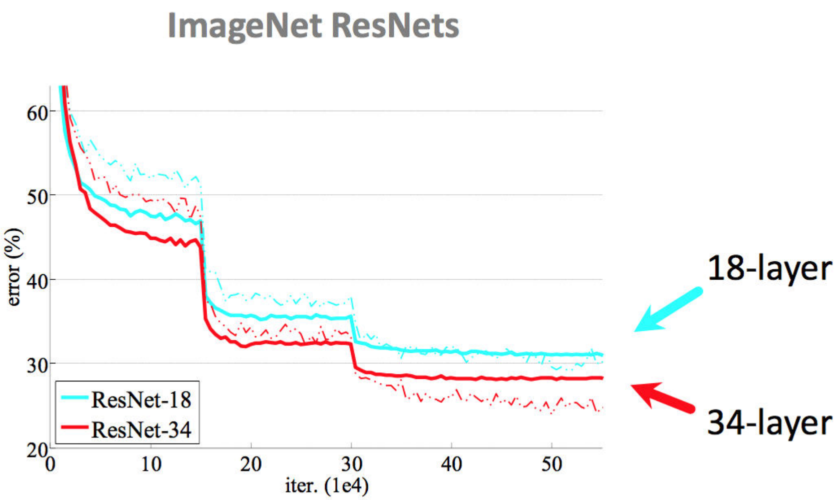


- Deep ResNets can be trained without difficulties
- Deeper ResNets have lower training error, and also lower test error

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. “Deep Residual Learning for Image Recognition”. arXiv 2015.

ImageNet experiments





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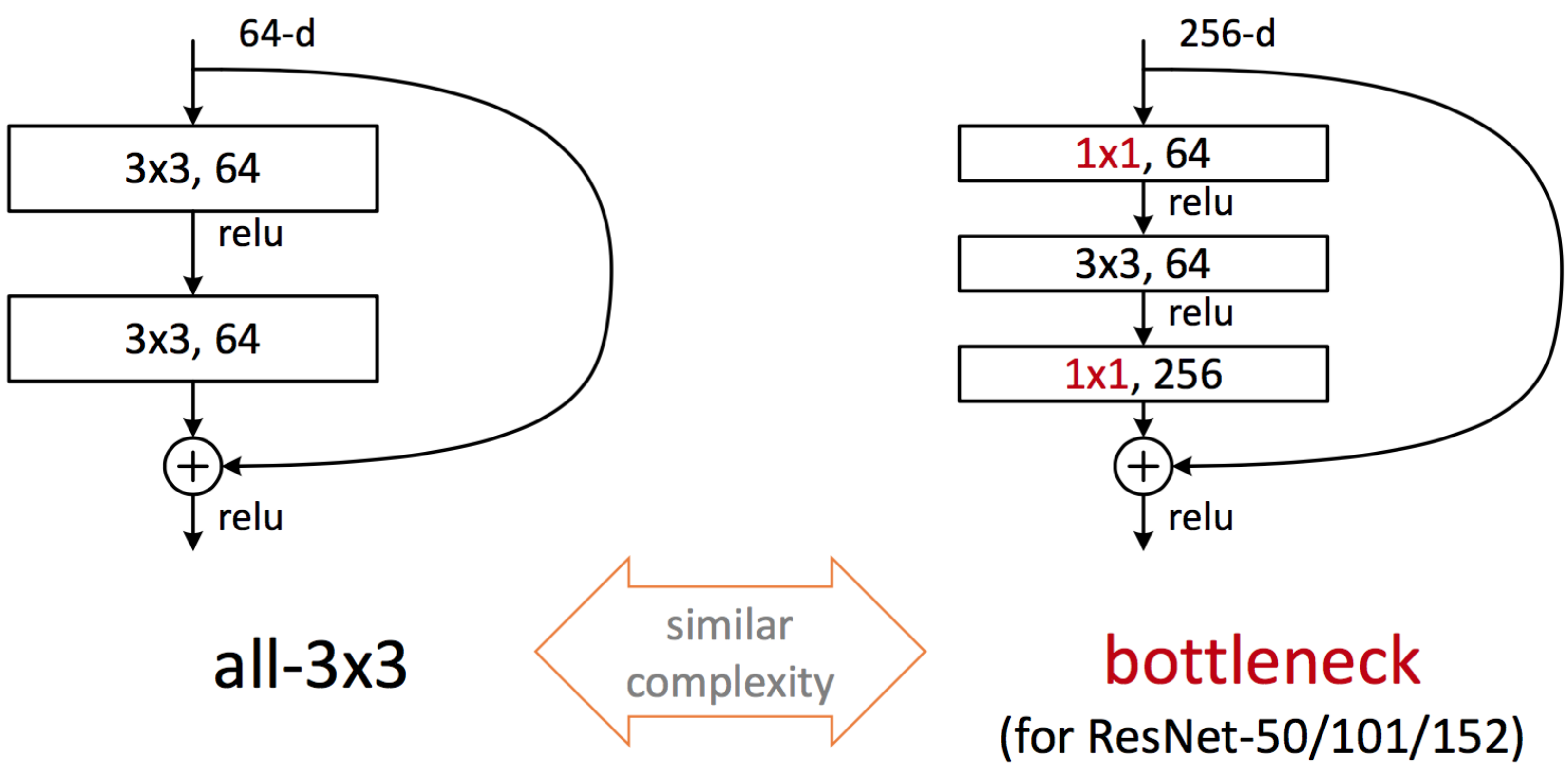
ImageNet experiments

- A practical design of going deeper



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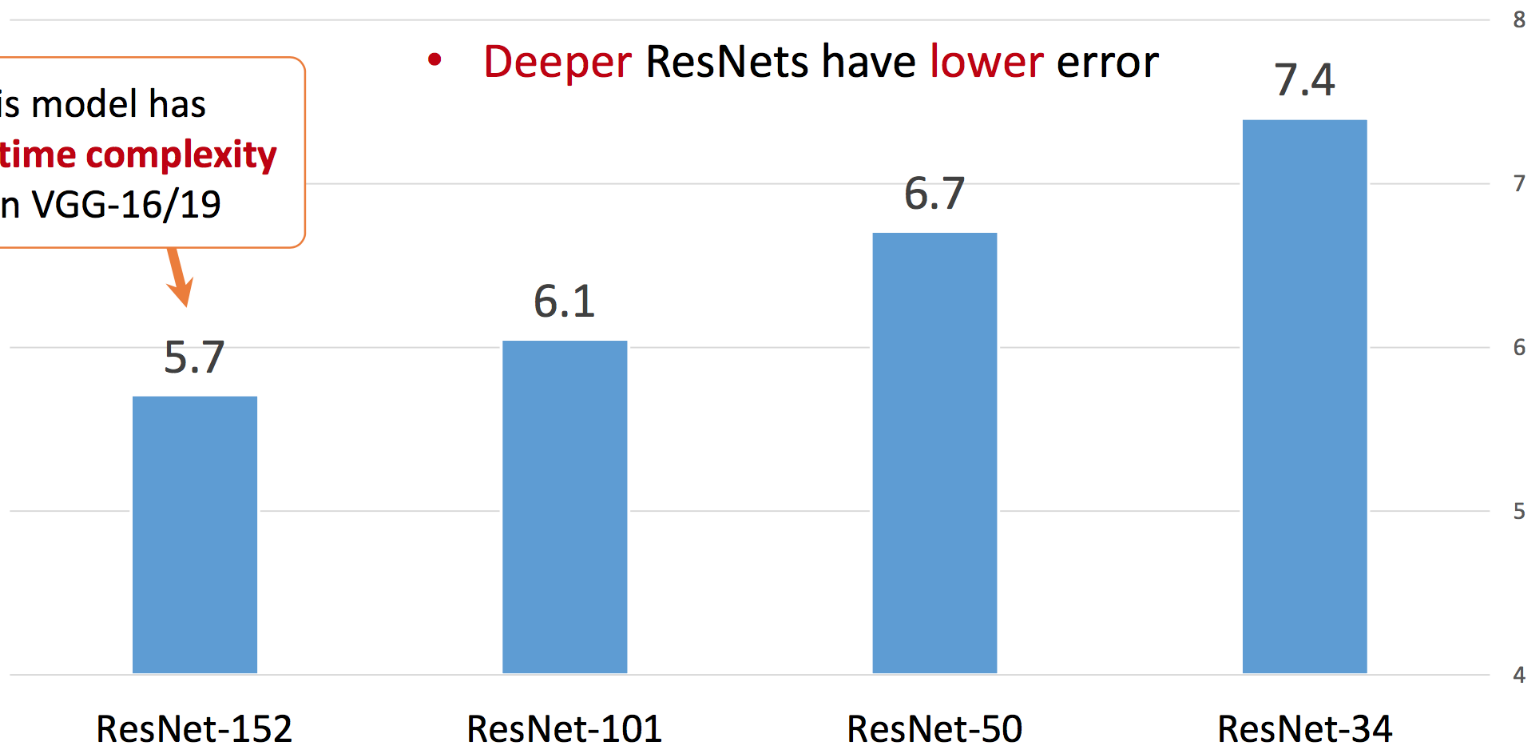
ImageNet experiments

- Deeper ResNets have lower error

this model has
lower time complexity
than VGG-16/19



10-crop testing, top-5 val error (%)

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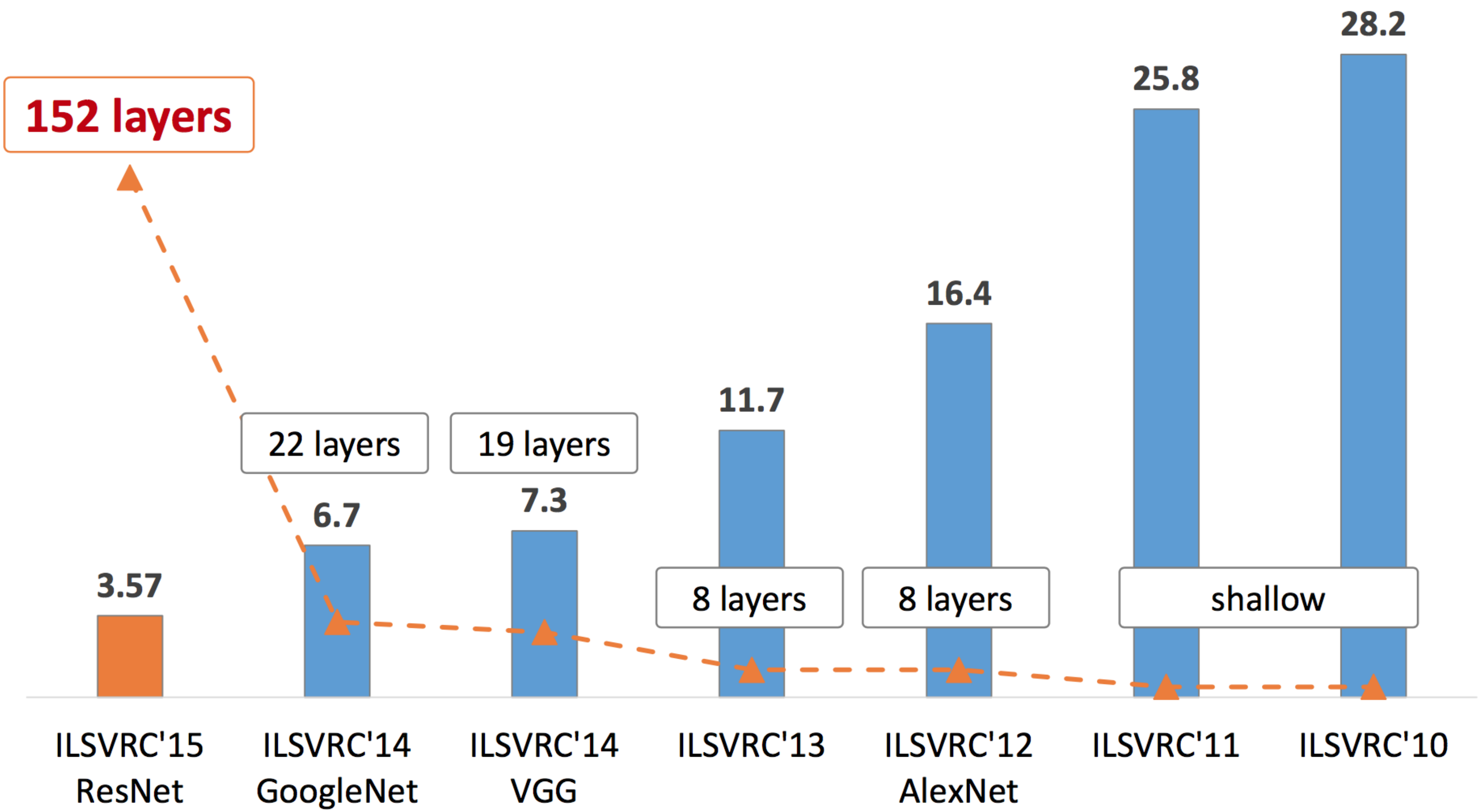
ImageNet experiments



ImageNet Classification top-5 error (%)

Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.

Exploring over 1000 layers

- Test 1202 layers
  - Training is finished
  - Training error is similar
  - Testing error is high because of over fitting

method			error (%)
Maxout [10]			9.38
NIN [25]			8.81
DSN [24]			8.22
	# layers	# params	
FitNet [35]	19	2.5M	8.39
Highway [42, 43]	19	2.3M	7.54 (7.72±0.16)
Highway [42, 43]	32	1.25M	8.80
ResNet	20	0.27M	8.75
ResNet	32	0.46M	7.51
ResNet	44	0.66M	7.17
ResNet	56	0.85M	6.97
ResNet	110	1.7M	**6.43** (6.61±0.16)
ResNet	1202	19.4M	7.93

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Conclusion

- Deep Residual Learning:
  - Ultra deep networks can be easy to train
- Ultra deep networks can gain accuracy from depth
- Ultra deep representations are well transferrable
- Now 200 layers on ImageNet and 1000 layers on CIFAR!

Reference

- Kaiming He, Xiangyu Zhang, Shaoqing Ren, & Jian Sun. "Deep Residual Learning for Image Recognition". arXiv 2015.
- Slides of Deep Residual Learning @ ILSVRC & COCO 2015 competitions

Thank You!