Quantifying the use of Domain Randomization

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Motivation

Synthetic world
Similar target textures

Real world

(Tobin et al.)

Domain Randomized (DR) Synthetic Images
Unknown target textures

(Tobin et al.)

Domain shift

Synthetic data distribution
(Source)

Real data distribution
(Target)

(DR) Synthetic Images


Motivation

Domain Randomization (DR) can broaden a synthetic data distribution to encompass a realistic data distribution. Use of Synthetic Data

No consensus on the optimal approach to applying DR — leading to inefficient sampling and unguided application.
Texture Randomization

Large amount of possible textures — which textures would result in the highest performance to solve a given task?

Patterned Textures
- Checkerboard
- Striped
- Zig-Zag

Non-Patterned Textures
- Flat RGB
- Gradient RGB

Additional Noise (Perlin)
- Checkerboard
- Striped
- Zig-Zag
- Flat RGB
- Gradient RGB


S. James, A. J. Davison, and E. Johns, “Transferring End-to-End Visuomotor Control from Simulation to Real World for a Multi-Stage Task,” 1st Conference on Robot Learning (CoRL), 2017

Typical Approach


Synthetic Data Generation

- Domain Randomization Routine
- Renderer
- Modify DR Data Distribution

Training

- Images
- Labels
- Train Task-Based Network

Location of Object (x,y,z)

Task-Based Network

Evaluation on Real Data
- Good Performance
- Poor Performance

Training Images

Images x
Typical Approach

Typical Approach

Synthetic Data Generation

Domain Randomization Routine → Renderer → Modify DR Data Distribution

Training

Images × Labels → Train Task-Based Network

Testing

Evaluation on Real Data → Good Performance

Poor Performance

Checkerboard
Striped
Flat RGB (Perlin)
Flat RGB
Gradient RGB (Perlin)
Gradient RGB

Goal

Quantifying the difference between realistic and DR data distributions.

Contributions

• Novel method of quantifying differences between DR data distributions and real-equivalent samples
• Our method avoids the expense of task-specific training and evaluation
• We show lower distance estimates between DR and real-equivalent distributions, generated without task-based training, corresponds to higher task-based performance
Proposed Solution

Fréchet Inception Distance (FID)

\[
d^2((m_{\text{aug}}, C_{\text{aug}}), (m_r, C_r)) = \|m_{\text{aug}} - m_r\|_2^2 + \text{Tr}(C_{\text{aug}} + C_r - 2(C_{\text{aug}}C_r)^{\frac{1}{2}})
\]

Wasserstein Distance

\[
W(P_r, P_{\text{aug}}) = \inf_{\gamma \in \Pi(P_r, P_{\text{aug}})} \mathbb{E}_{(x, y) \sim \gamma} [\|x - y\|]
\]
Method

\[
L = \mathbb{E}_{\hat{x} \sim P_{\text{aug}}} \left[ D(\hat{x}) \right] - \mathbb{E}_{x \sim P_r} \left[ D(x) \right] + \lambda \mathbb{E}_{\tilde{x} \sim P_{\tilde{x}}} \left[ \left( \| \nabla_{\tilde{x}} D(\tilde{x}) \|_2 - 1 \right)^2 \right]
\]

\[
d^2((m_{\text{aug}}, C_{\text{aug}}), (m_r, C_r)) = \|m_{\text{aug}} - m_r\|^2 + \text{Tr}(C_{\text{aug}} + C_r - 2(C_{\text{aug}}C_r)^{\frac{1}{2}})
\]
Results

![Localization Task Error](chart)

Augmentations:
- Real Texture
- Zig Zag
- Striped Perlin
- Striped
- Zig Zag Perlin
- Checkerboard
- Flat RGB Perlin
- Gradient RGB Perlin
- Flat RGB
- Gradient RGB

Normalized Values (Lower is Better)
Results

FID Estimate

Localization Task Error
Results

Wasserstein Distance Estimate

Localization Task Error
Results

Patterned Textures

Zig-Zag
Striped
Checkerboard

Non-Patterned Textures

Flat RGB
Gradient RGB

Augmentations

Normalized Values (Lower is Better)

Localization Task Error
Wasserstein Distance Estimate
FID
Conclusion

• We propose a novel method of quantifying differences between DR data distributions and real-equivalent samples.

• We demonstrate that the method is capable of ranking the different augmentations which is reflected in the performance of an object localization task.

• Based on the produced ranking, generated without task-based training, we recommend using more complex patterned textures when generating DR synthetic data.
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