Multiplexed Metropolis Light Transport

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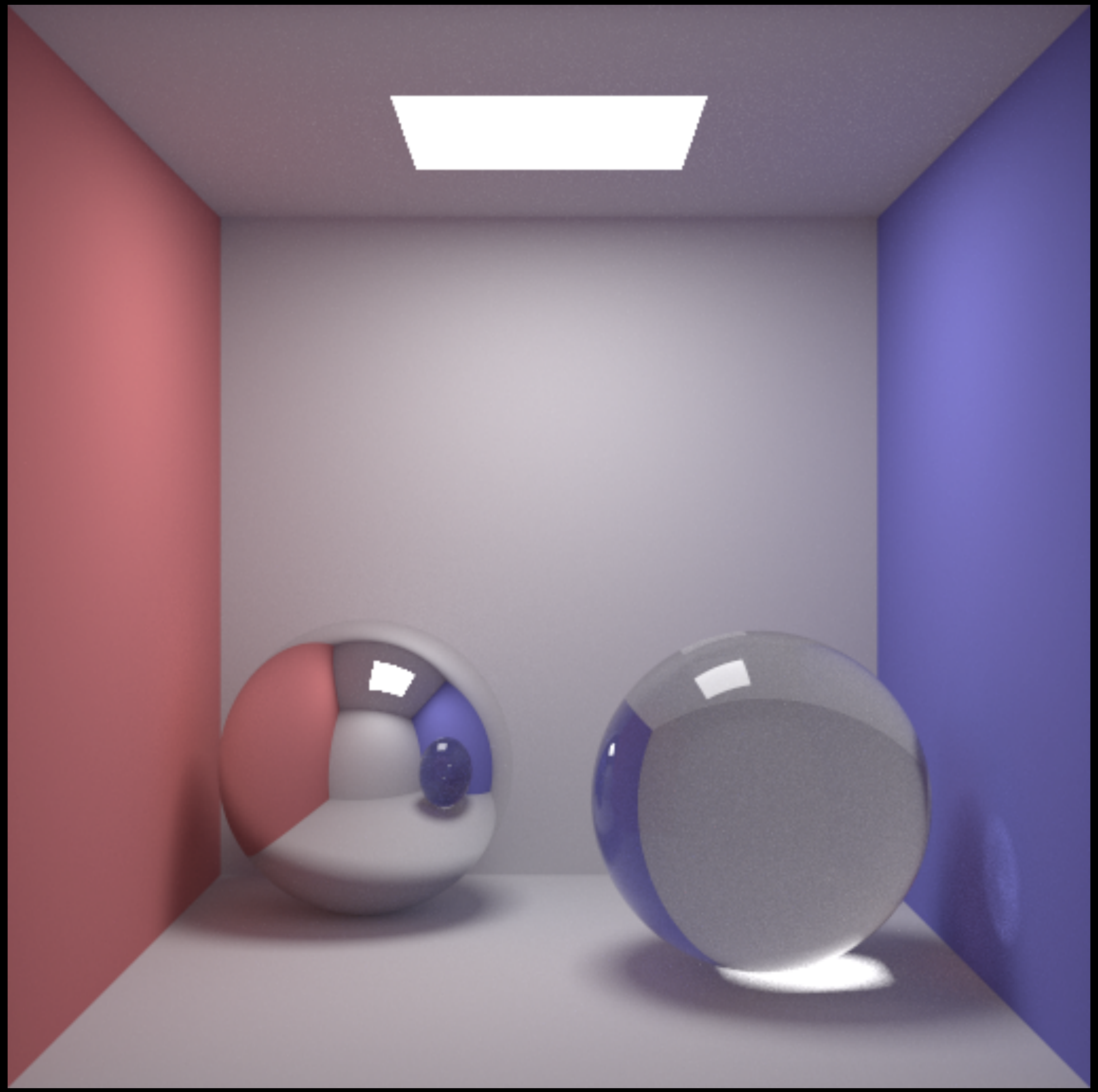
SIGGRAPH 2014

Two classes of MC methods

- Ordinary Monte Carlo



- Markov chain Monte Carlo

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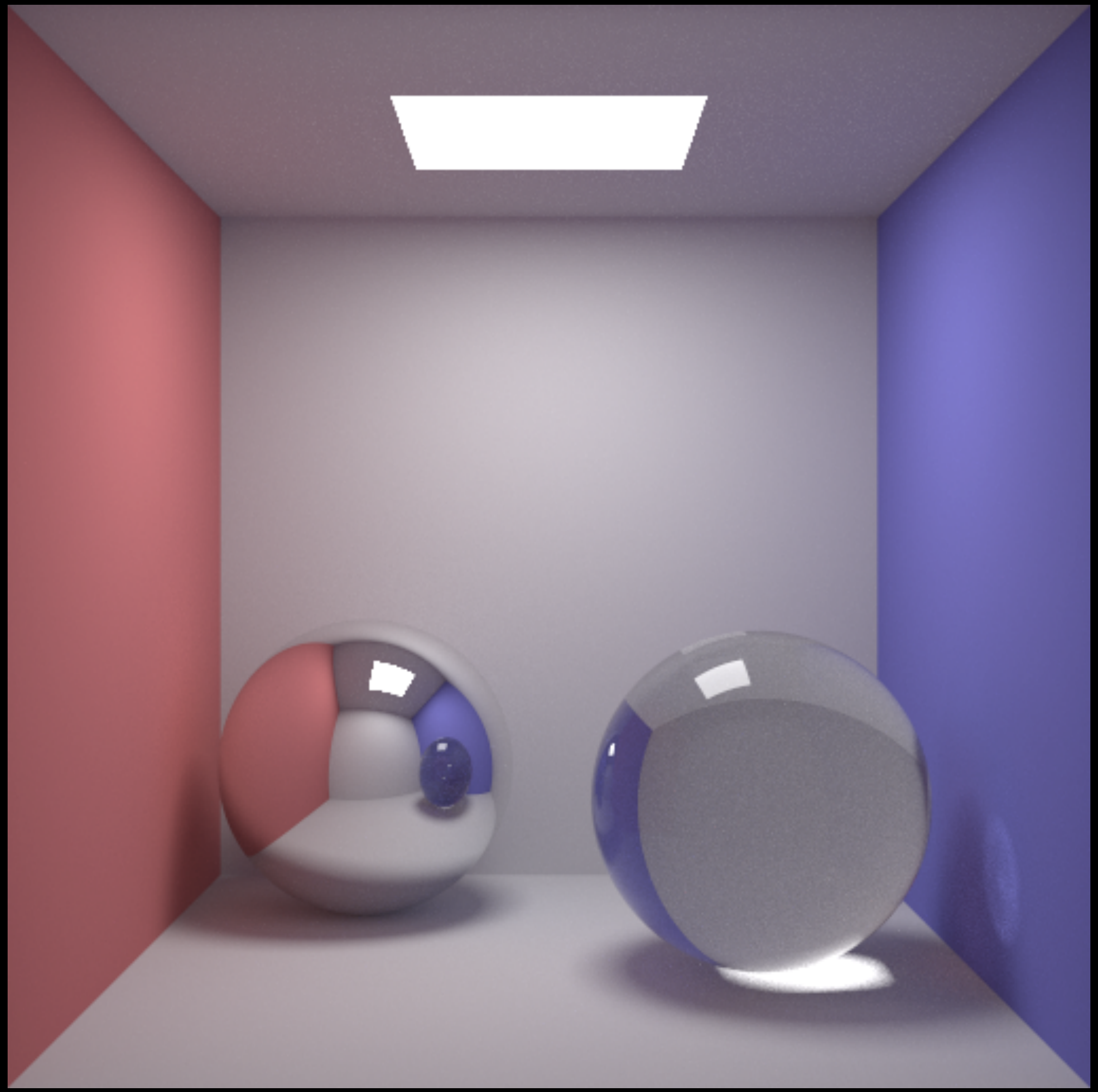


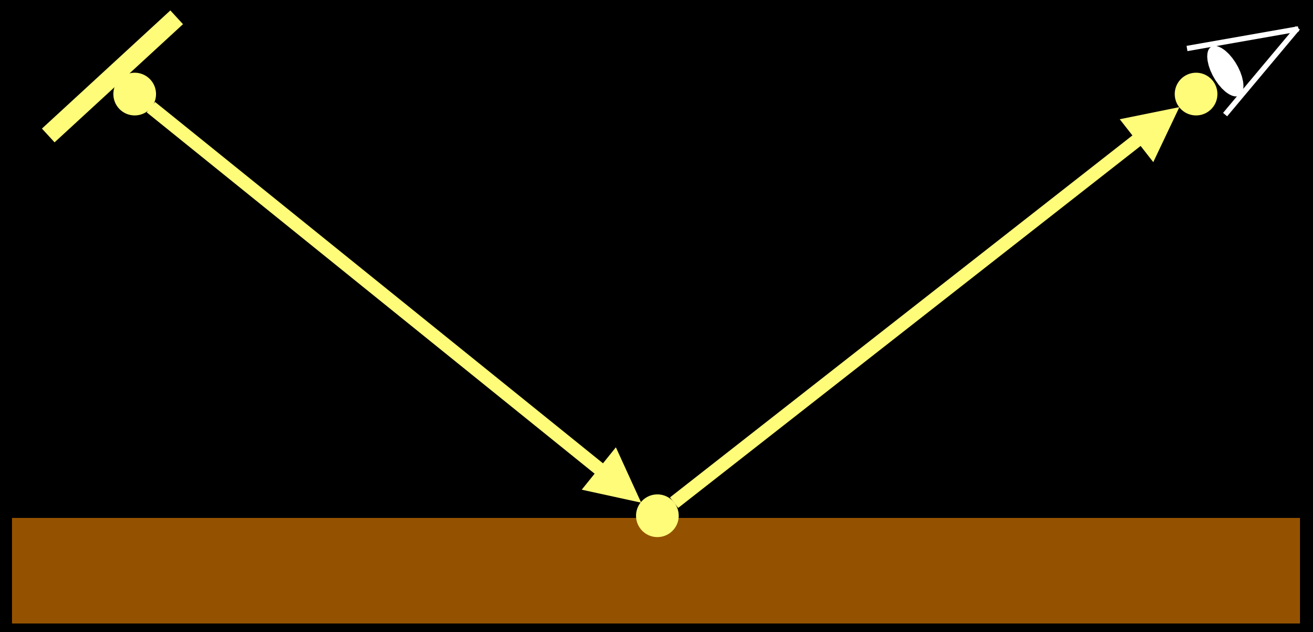
- Markov chain Monte Carlo

Ordinary Monte Carlo

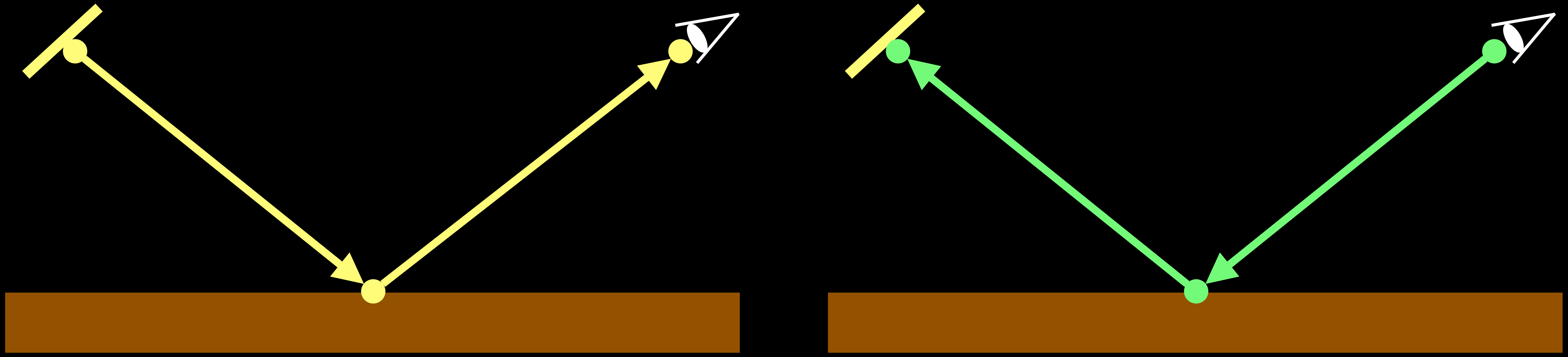
- Generate independent samples from a known PDF
  - We know how to integrate and invert this PDF

- Multiple importance sampling [Veach and Guibas 95]
  - Utilizes multiple known PDFs

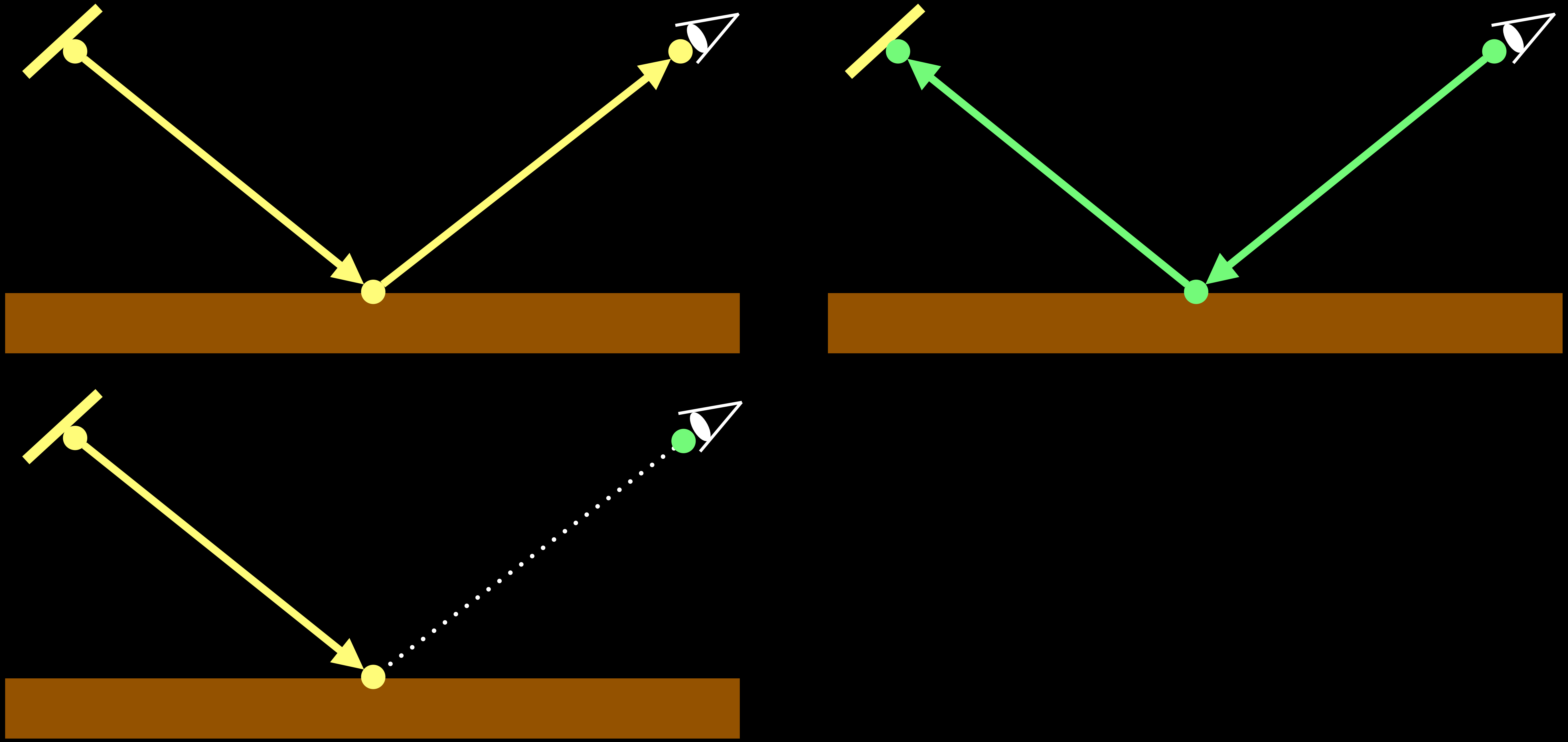
Multiple sampling methods



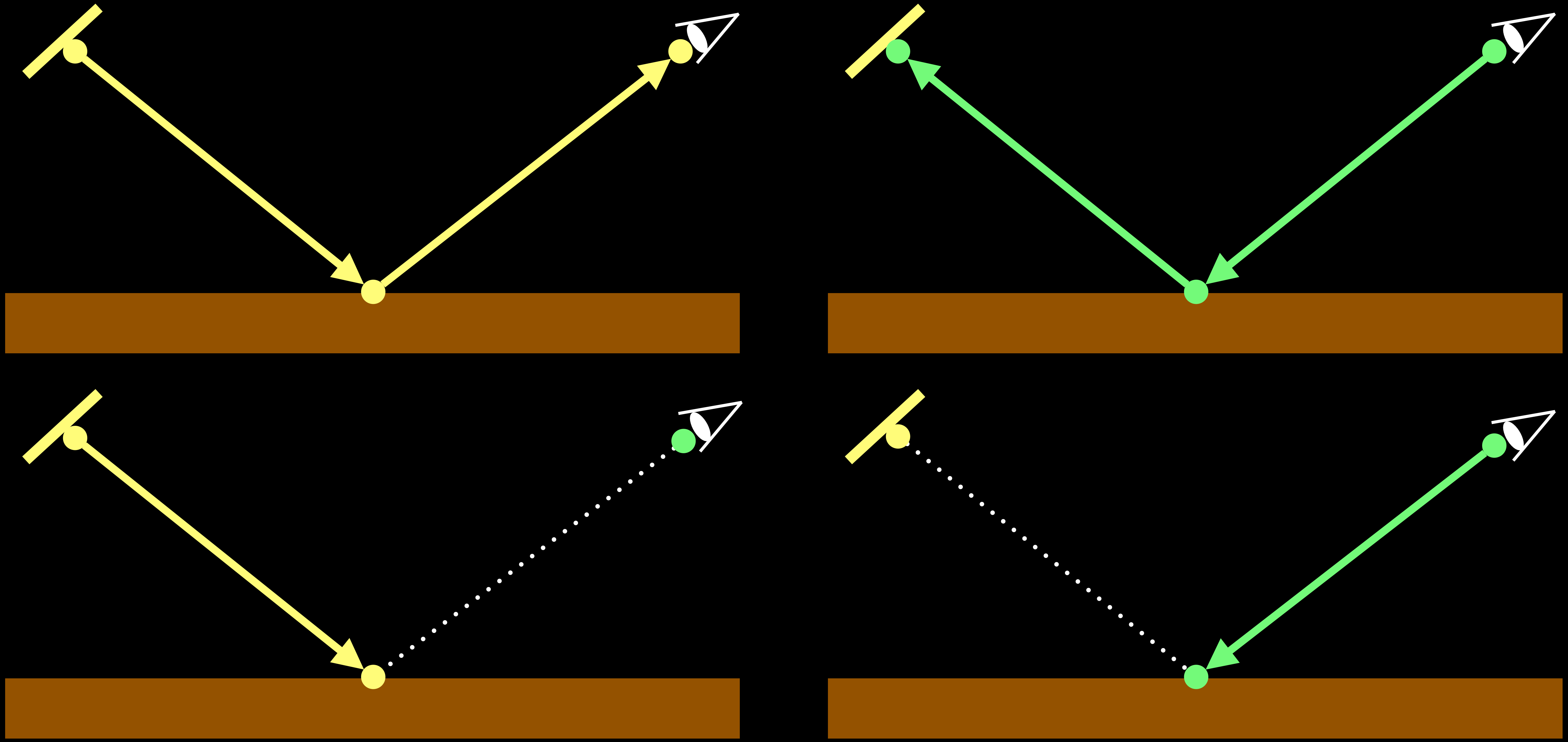
Multiple sampling methods



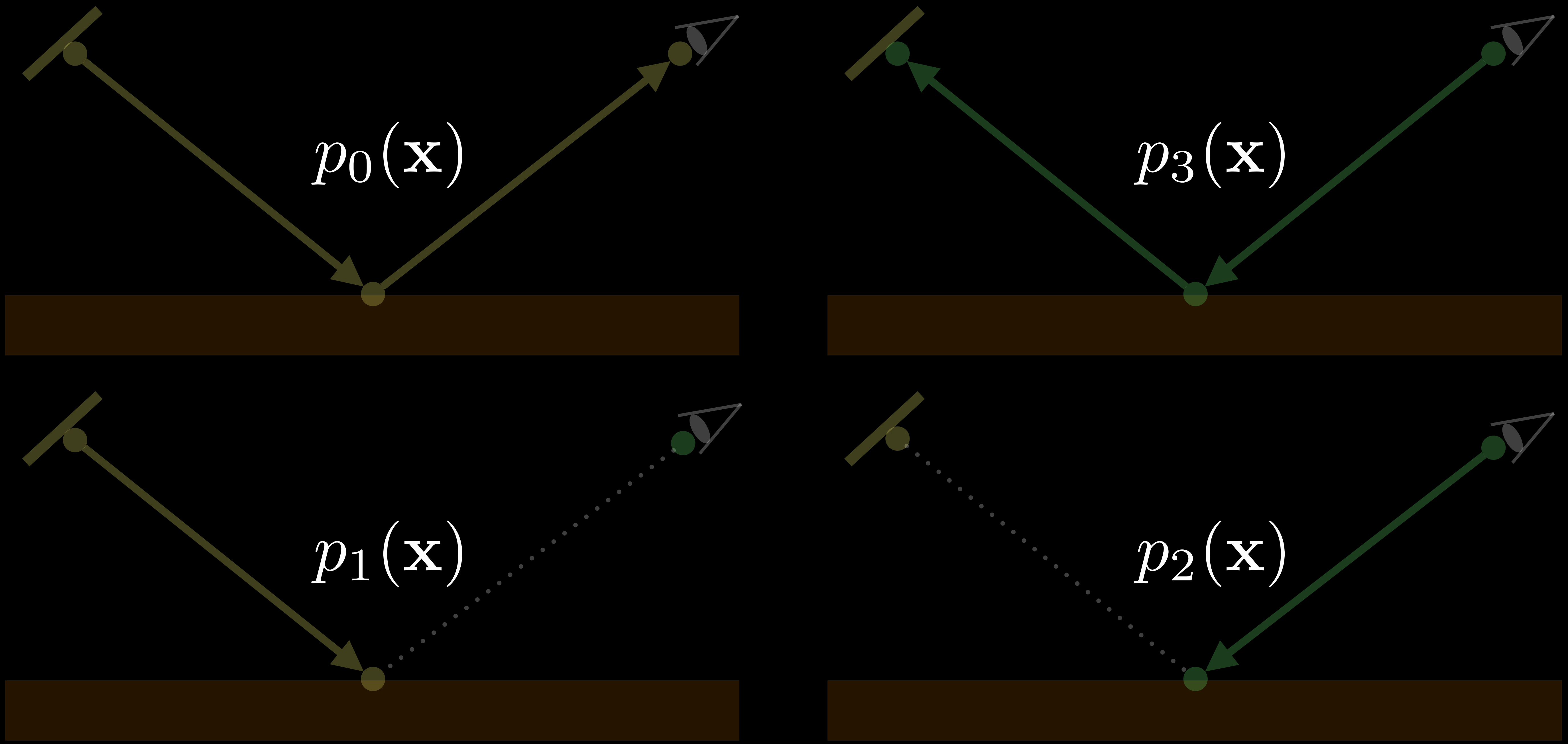
Multiple sampling methods



Multiple sampling methods

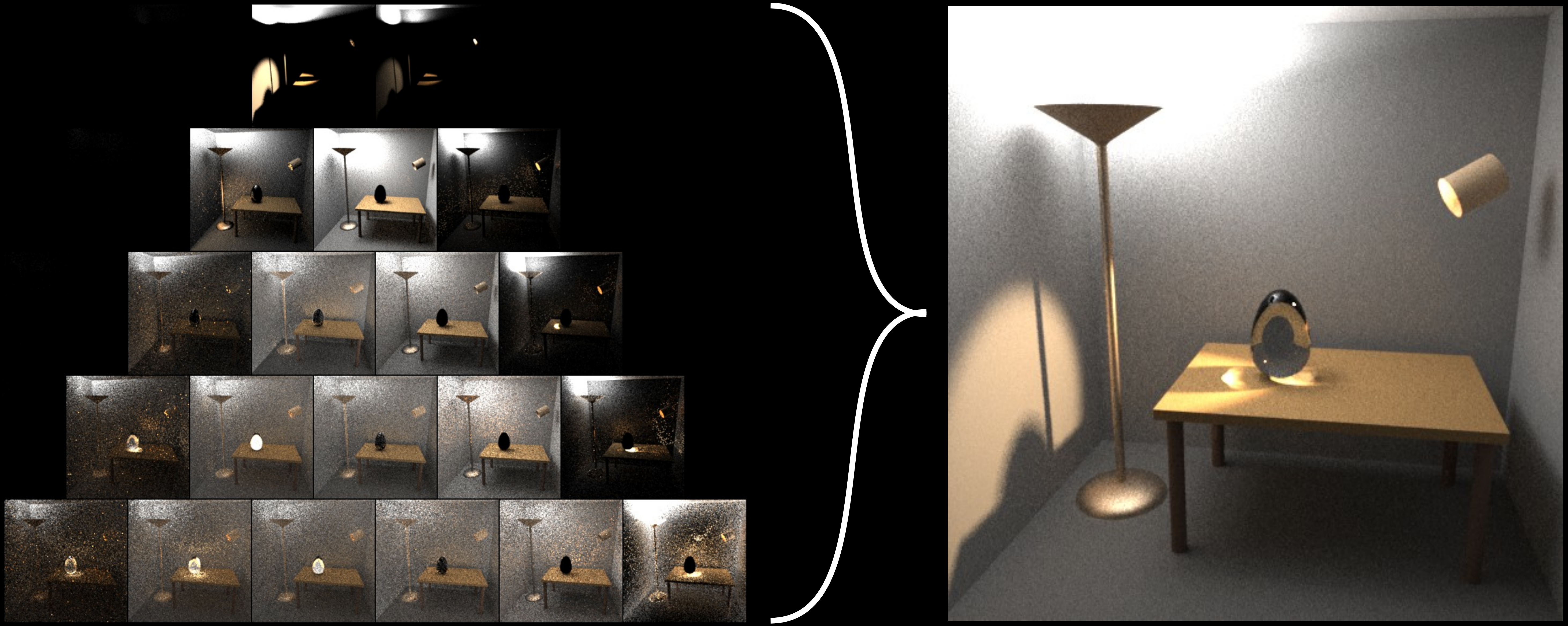


Multiple sampling methods



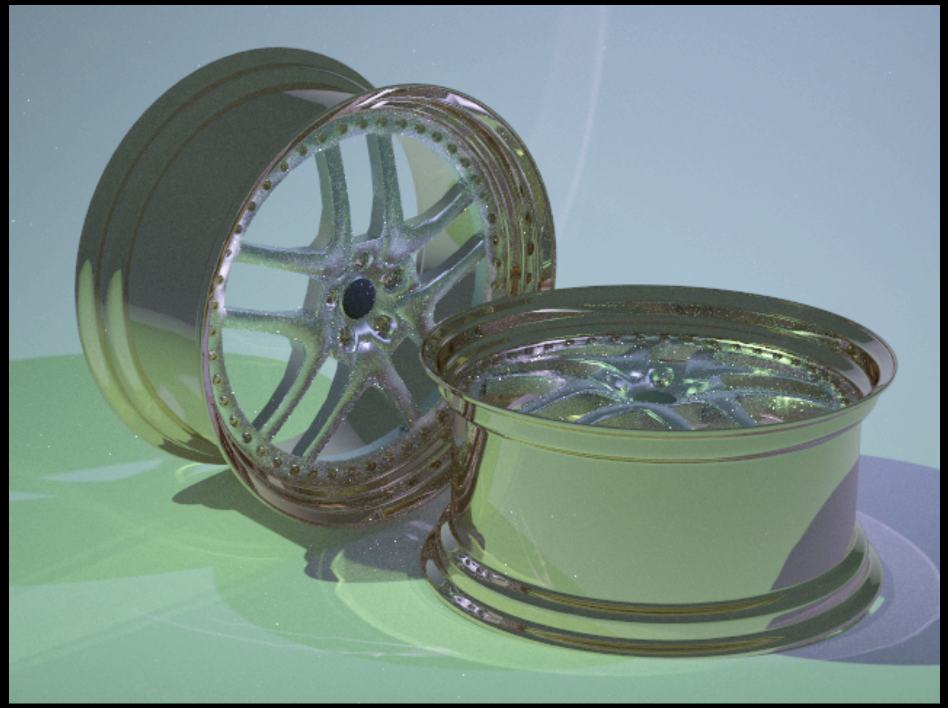
Bidirectional path tracing

- Uses MIS to combine multiple sampling techniques



MIS is a hot topic

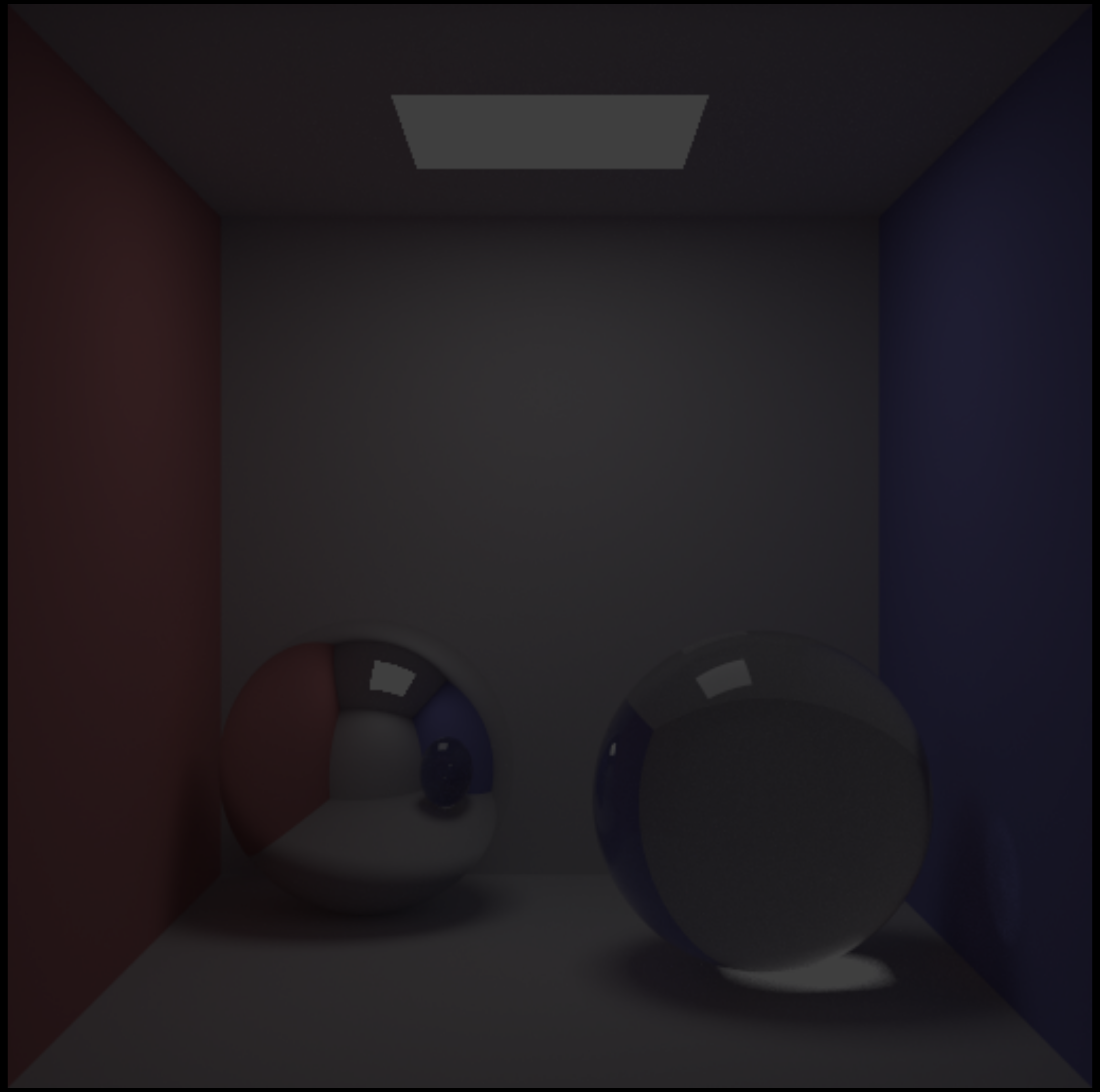
- UPS = VCM [Hachisuka et al. 12, Georgiev et al. 12]
- Bidirectional lightcuts [Walter et al. 12]
- Unified points/beams/paths [Krivanek et al. 14]



[Hachisuka et al. 12]

Two classes of MC methods

- Ordinary Monte Carlo



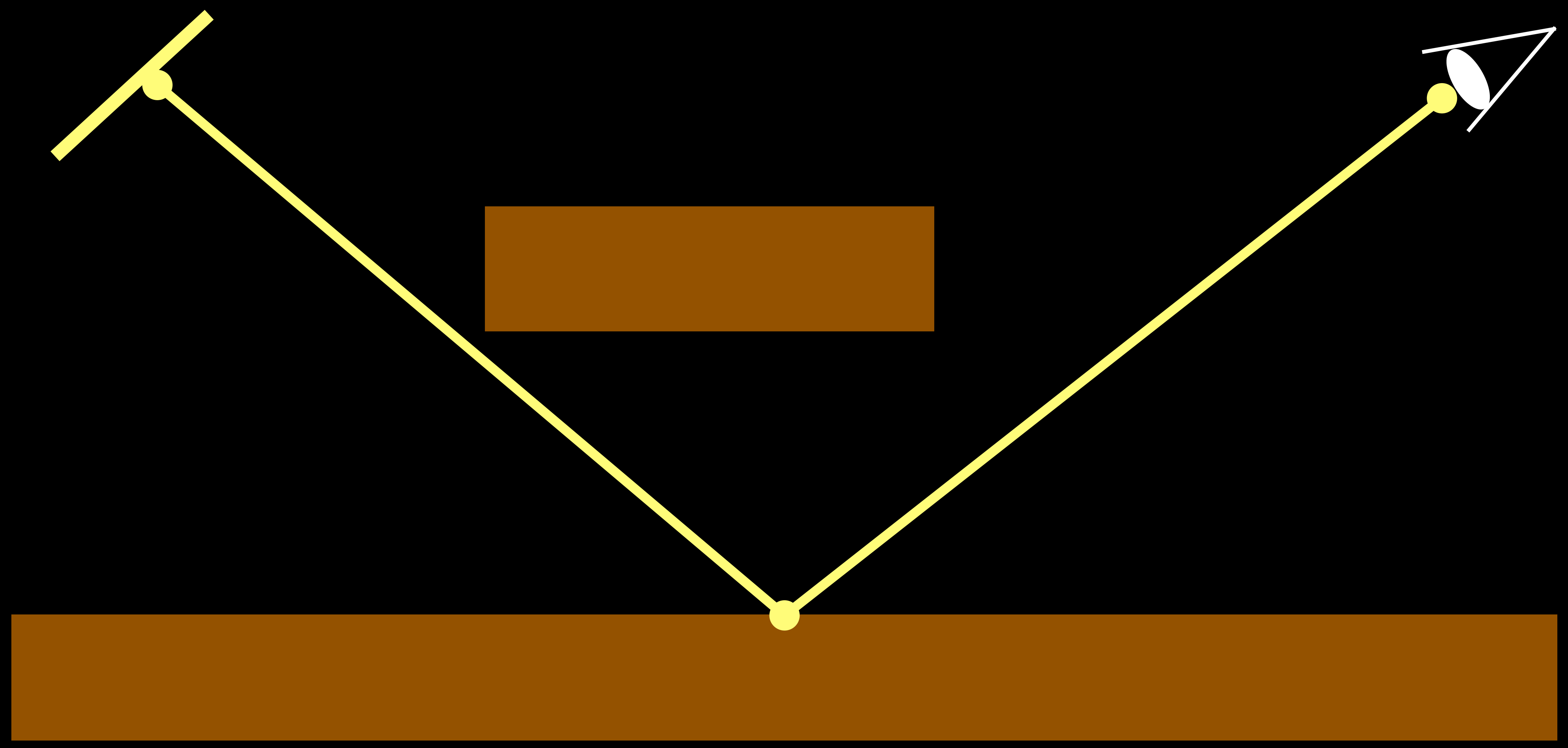
- Markov chain Monte Carlo

Markov chain Monte Carlo

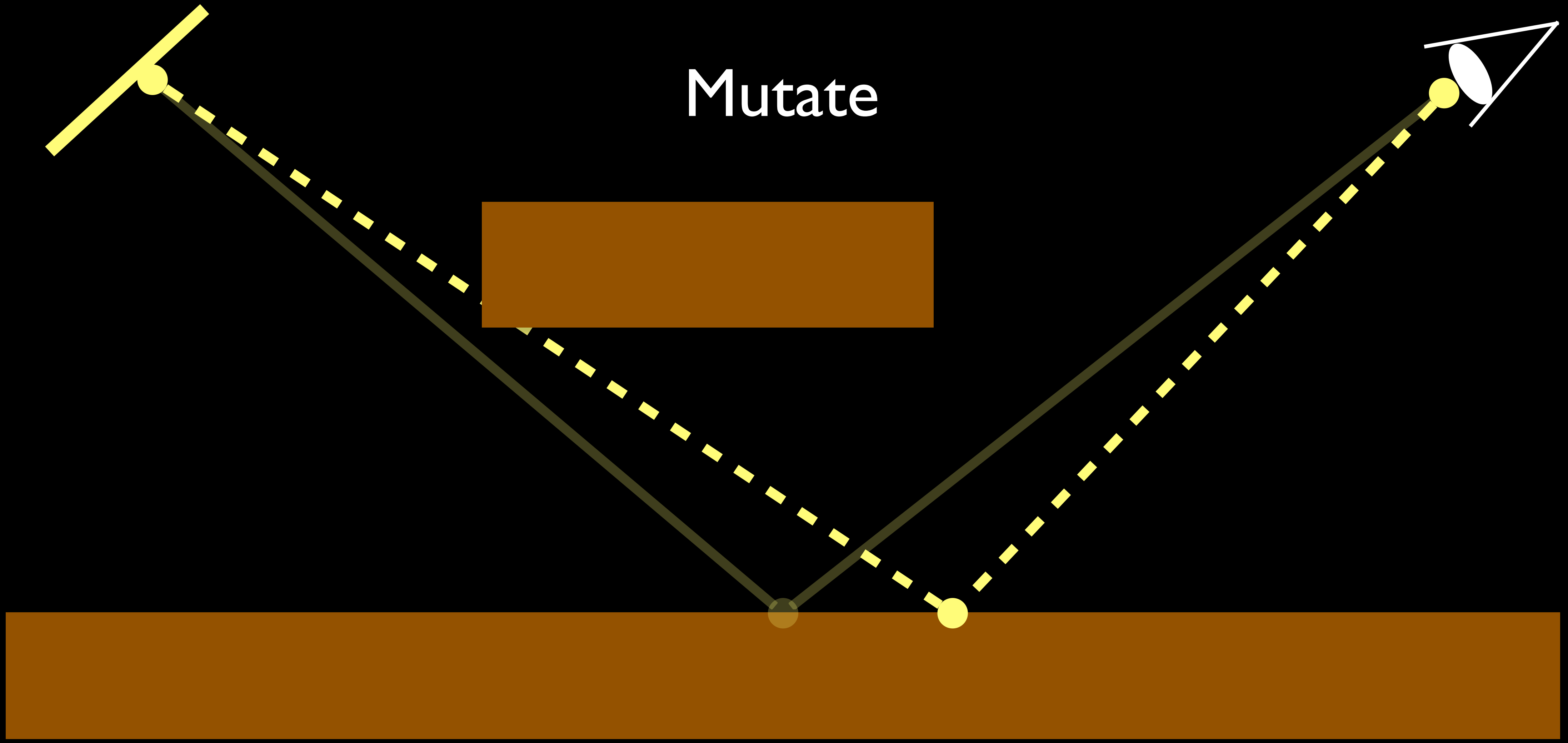
- Generate correlated samples from ***any* distribution**
  - Can sample paths based on contributions (visibility etc.)

- Metropolis light transport [Veach and Guibas 97]

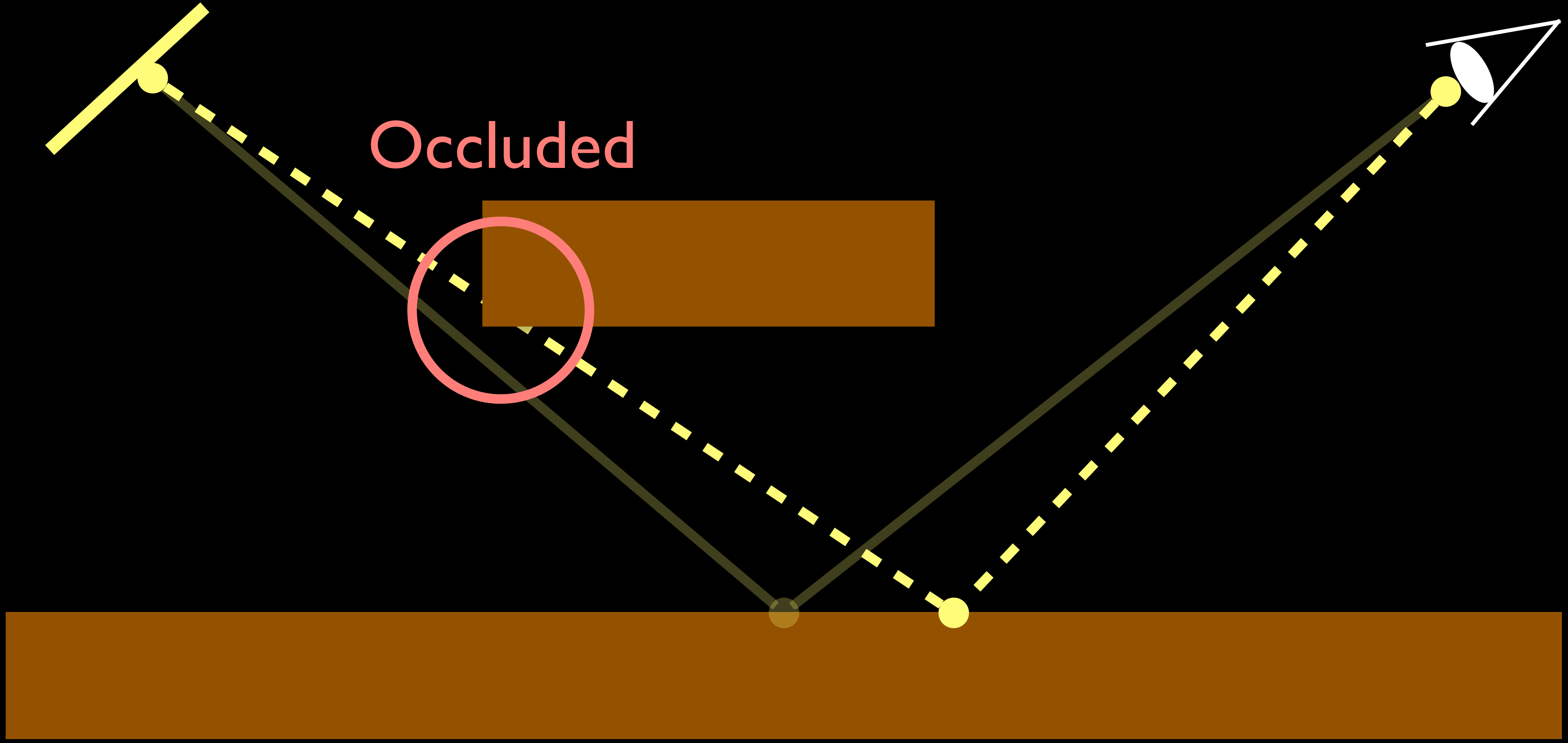
Markov chain Monte Carlo



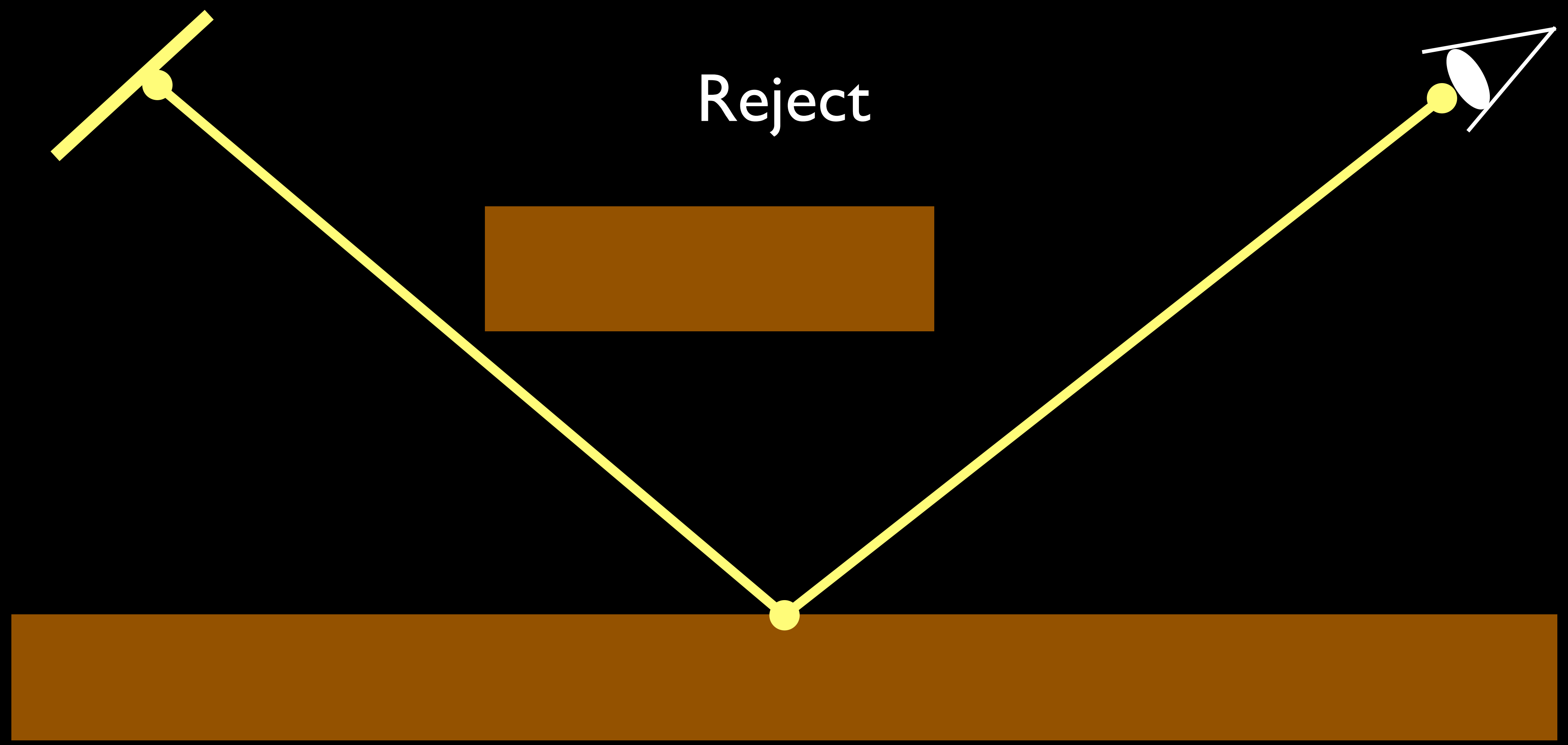
Markov chain Monte Carlo



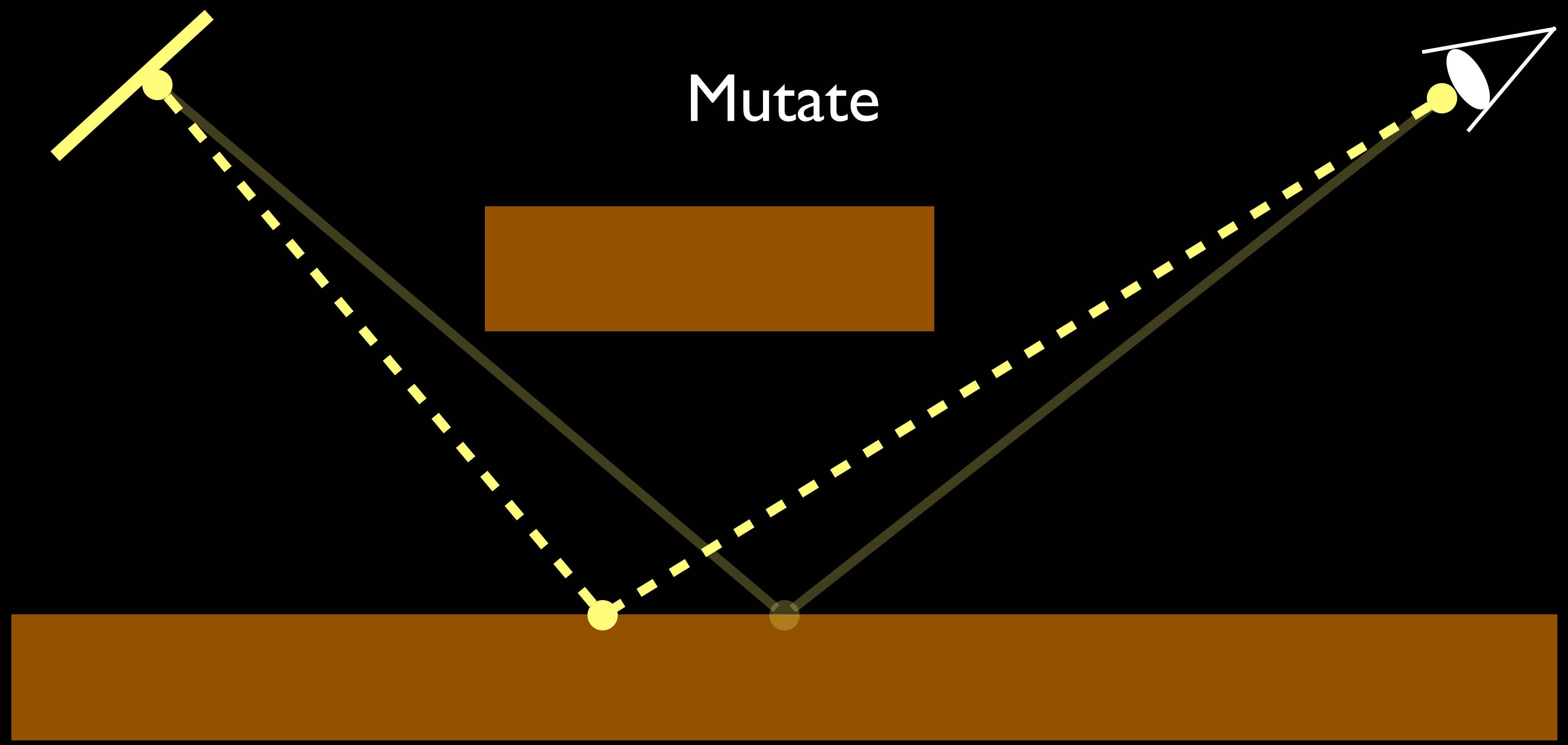
Markov chain Monte Carlo



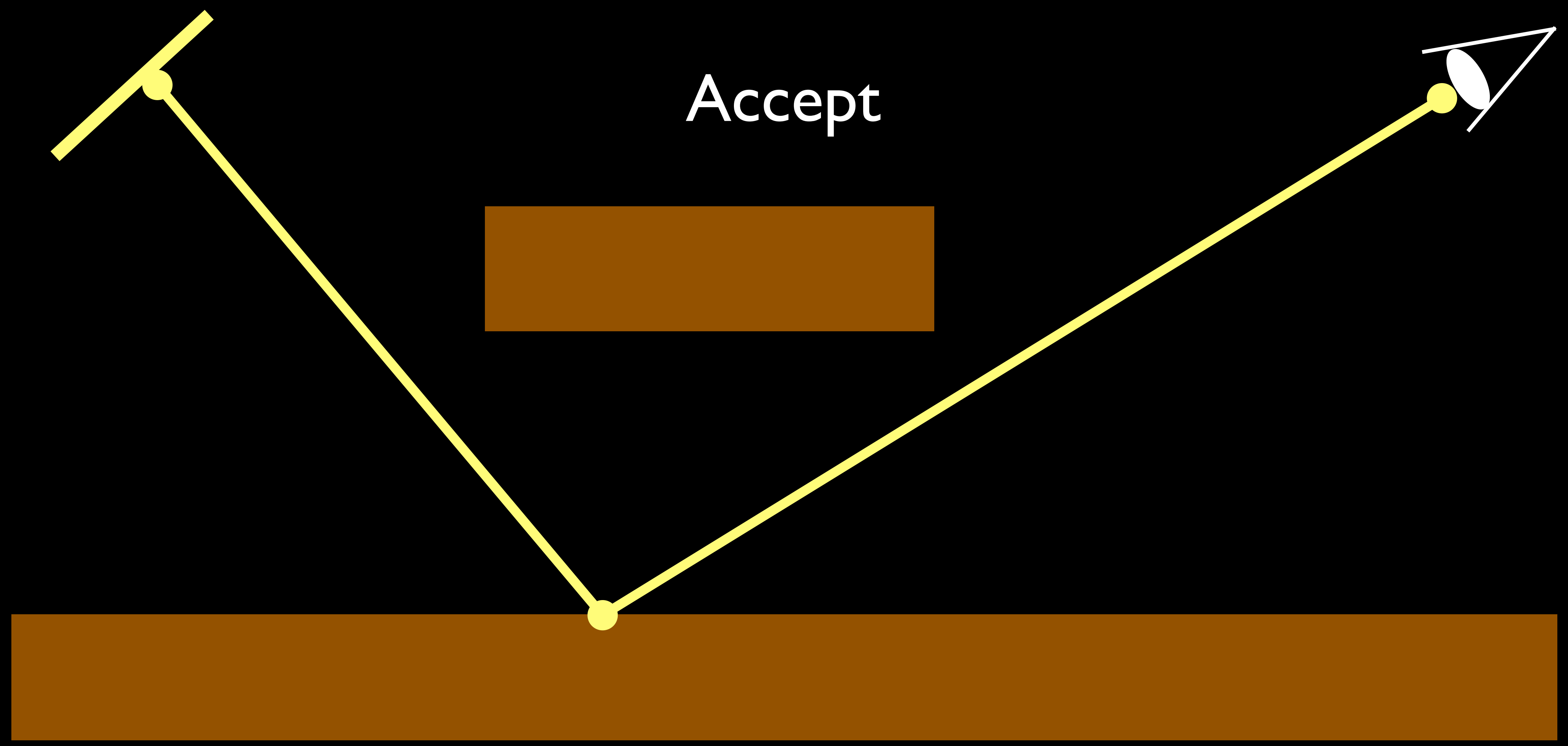
Markov chain Monte Carlo



Markov chain Monte Carlo



Markov chain Monte Carlo



Metropolis light transport

MCMC is also a hot topic

- Manifold exploration [Jakob and Marschner 12]
- Gradient-domain MLT [Lehtinen et al. 13]
- Half-vector MLT [Kaplanyan et al. 14]

[Jakob and Marschner 12]

	Multiple techniques	Arbitrary distribution
Ordinary MC	Yes (via MIS)	No

	Multiple techniques	Arbitrary distribution
Ordinary MC	Yes (via MIS)	No
MCMC	No	Yes

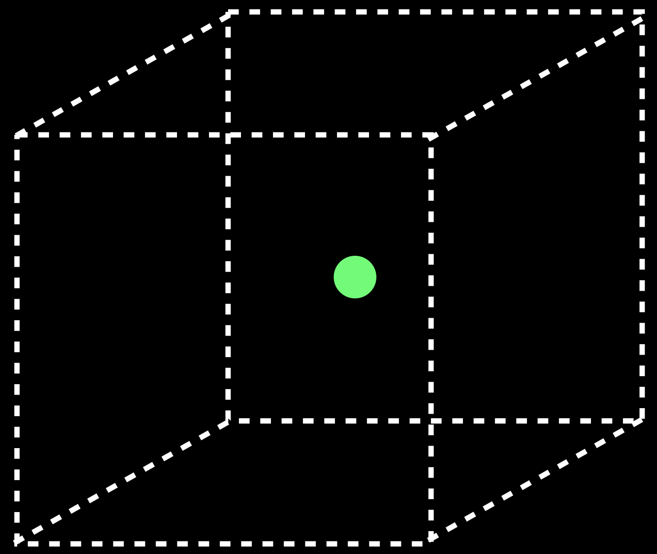
Question

	Multiple techniques	Arbitrary distribution
Ordinary MC	Yes (via MIS)	No
MCMC	No	Yes
?	Yes	Yes

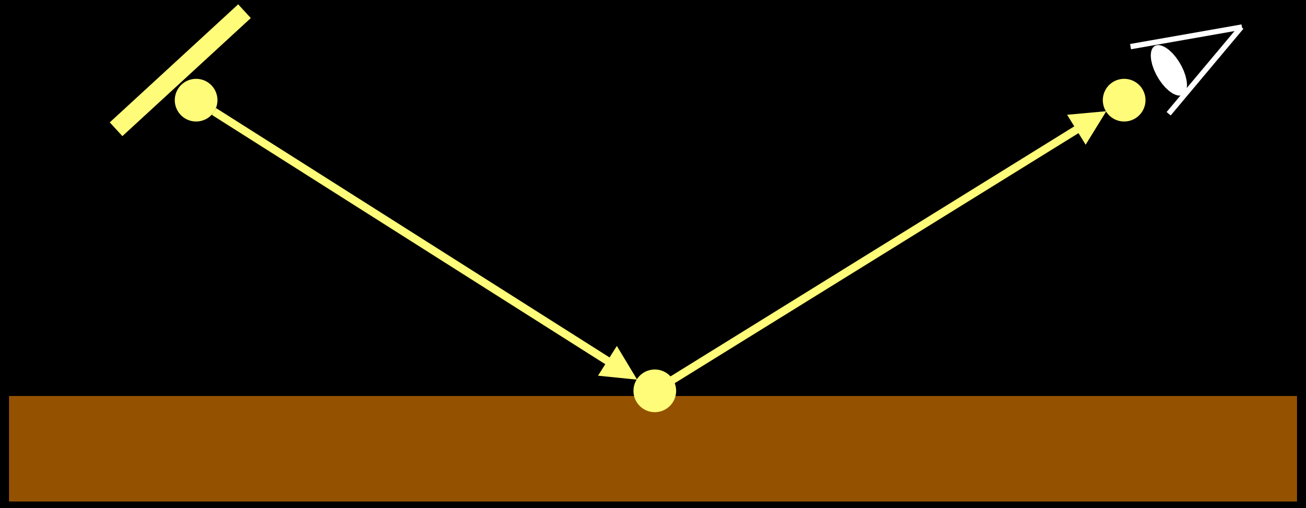
Multiplexed MLT

Primary sample space

- Hypercube of random numbers $\bar{U} \in]0,1[^N$
  - Mapping from a point to the path = Inverse CDF
  - Introduced by Kelemen et al. [2002]



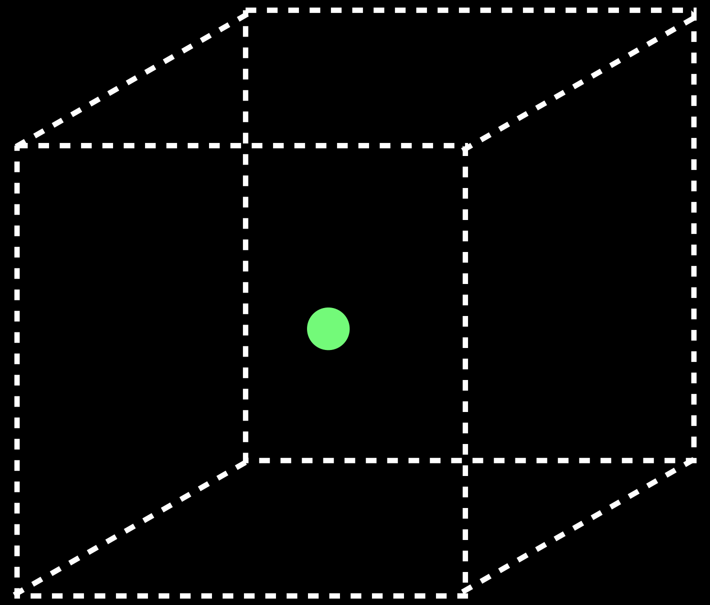
$\bar{X} = P^{-1}(\bar{U})$



Point in the hypercube

Path in the object space

Primary sample space MLT



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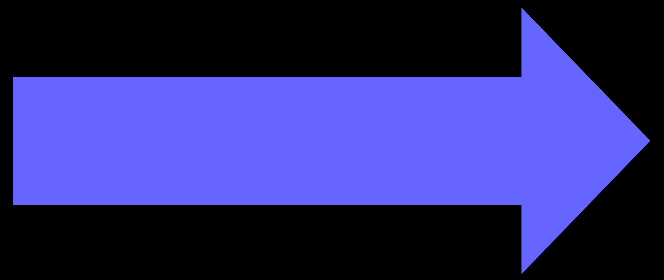
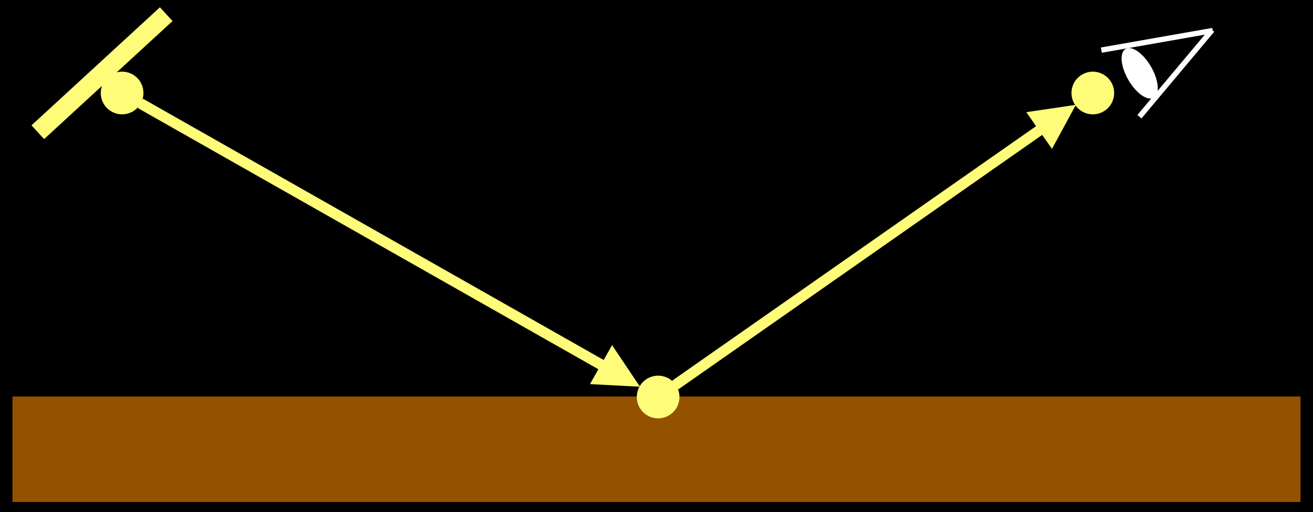
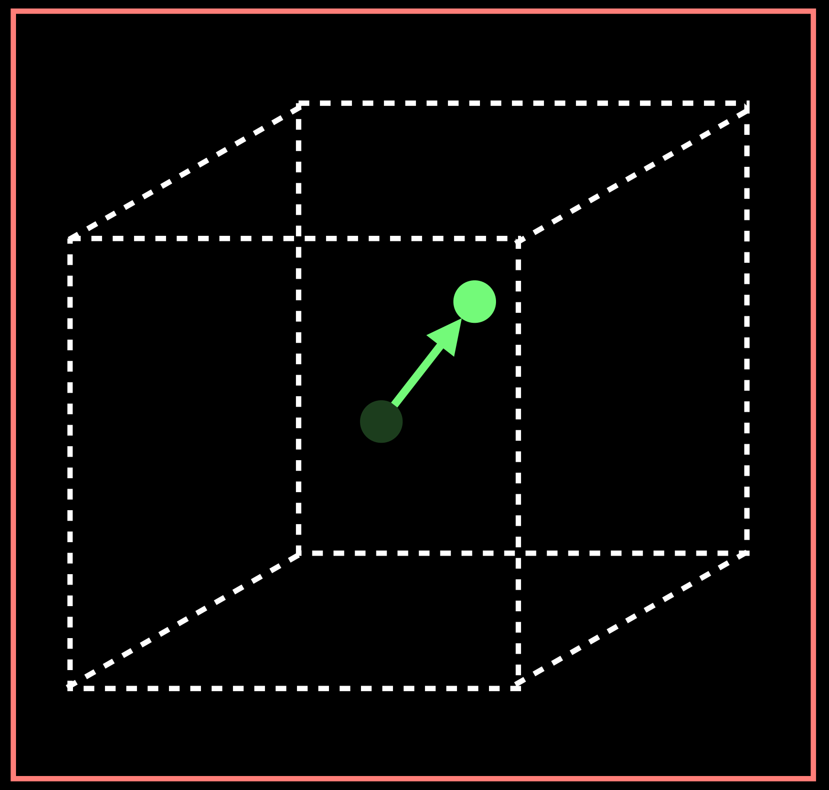




Primary sample space MLT



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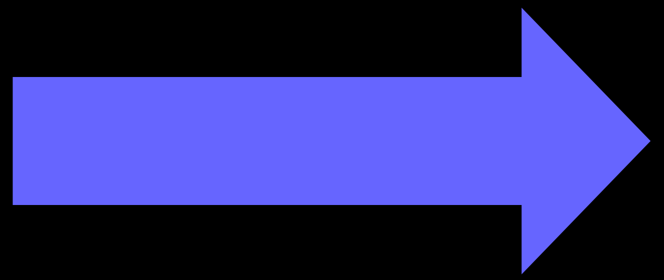
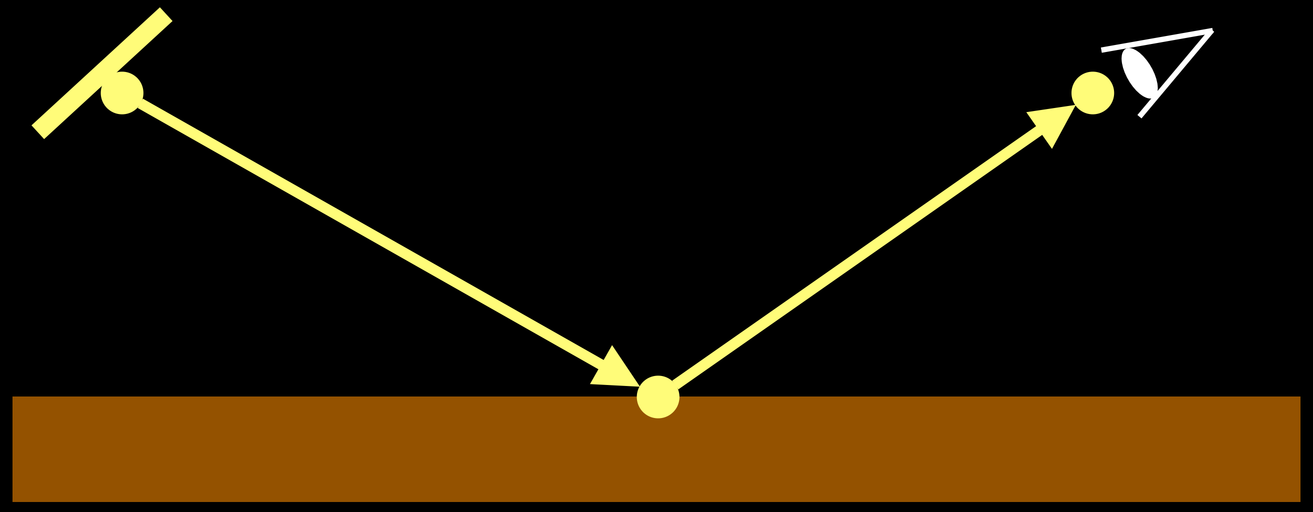
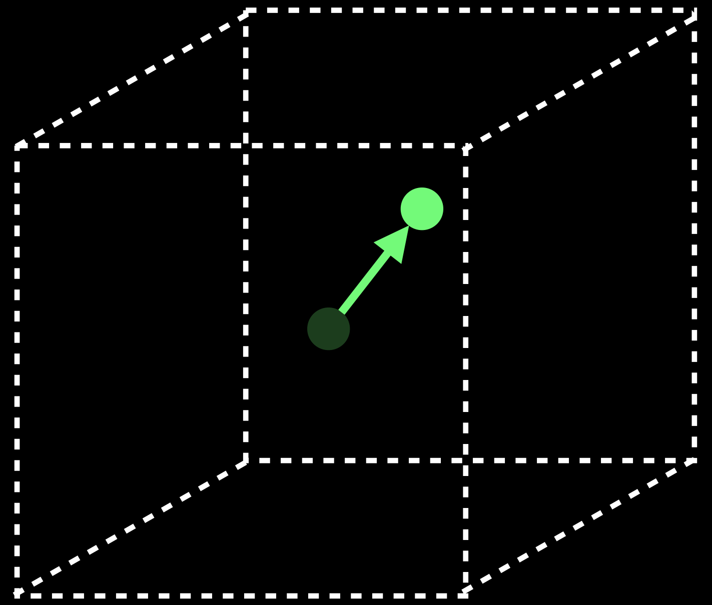




Primary sample space MLT



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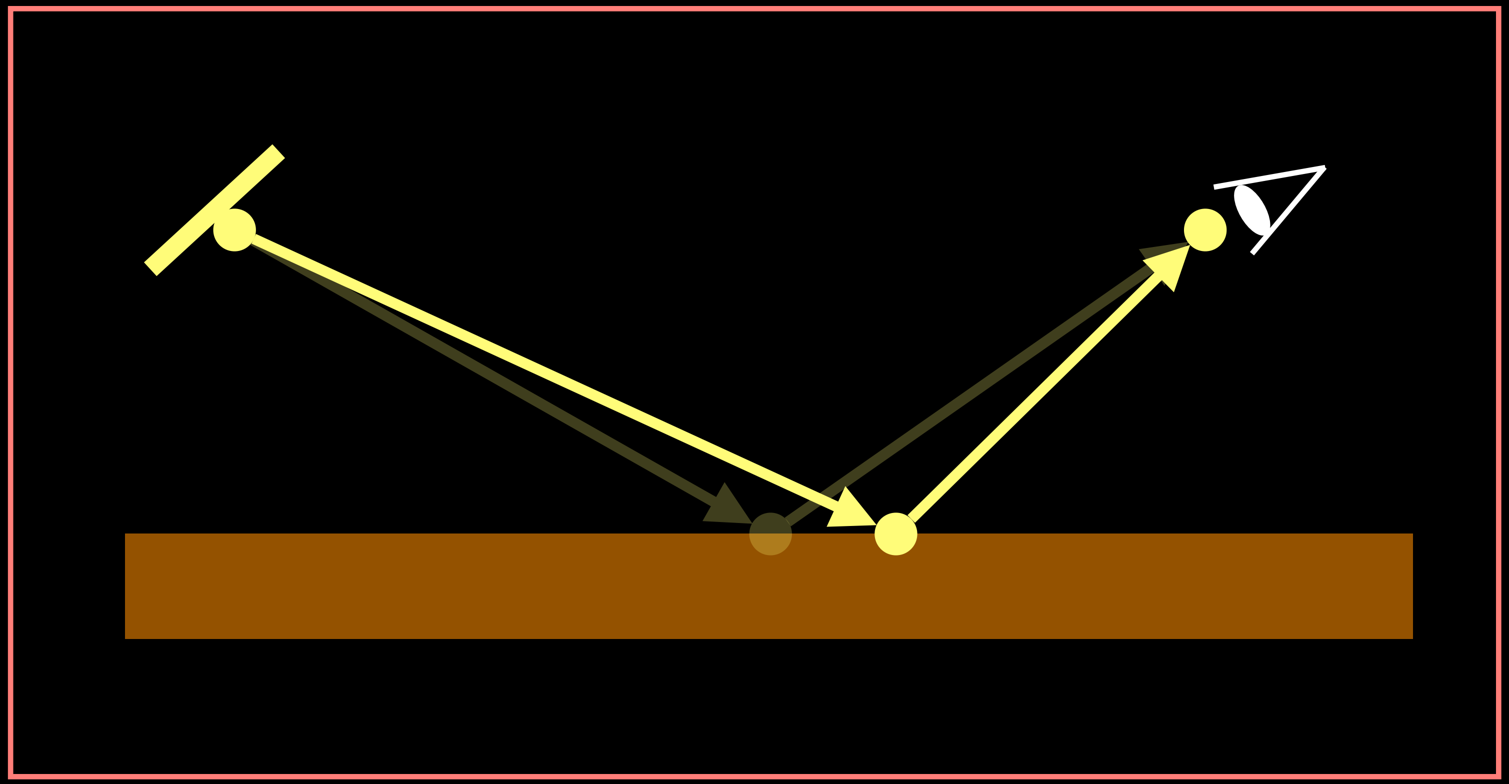

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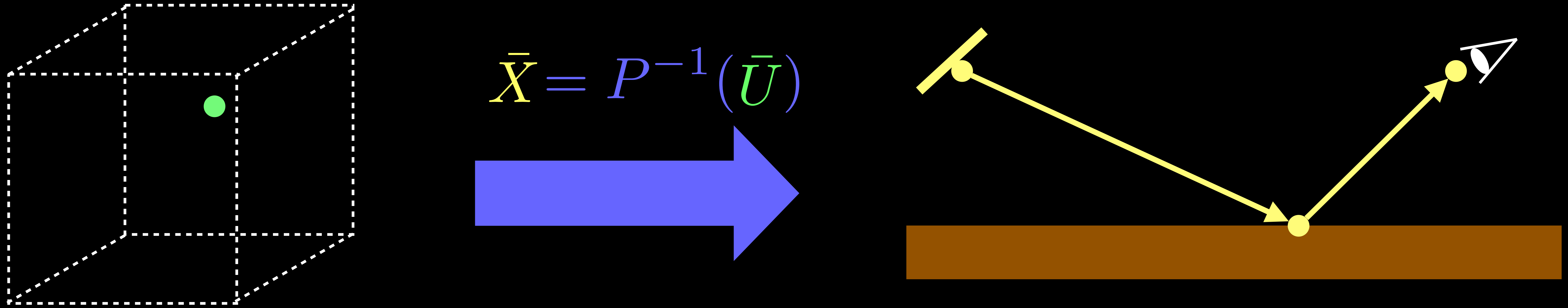

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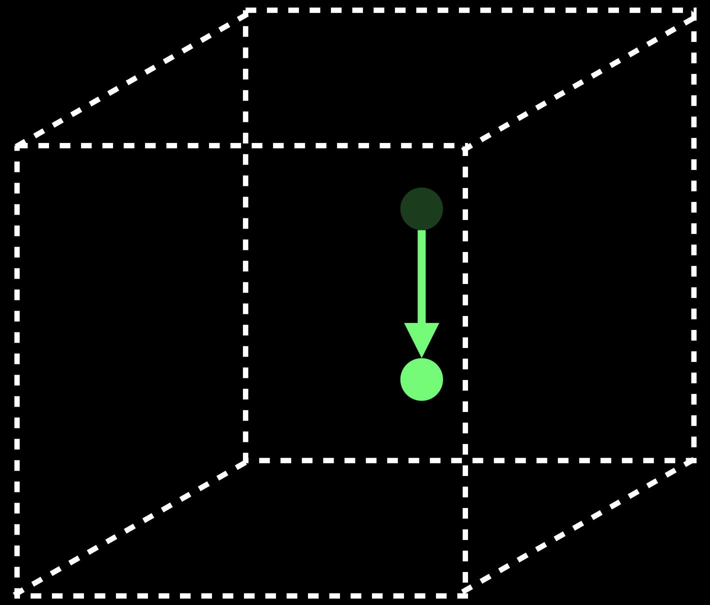

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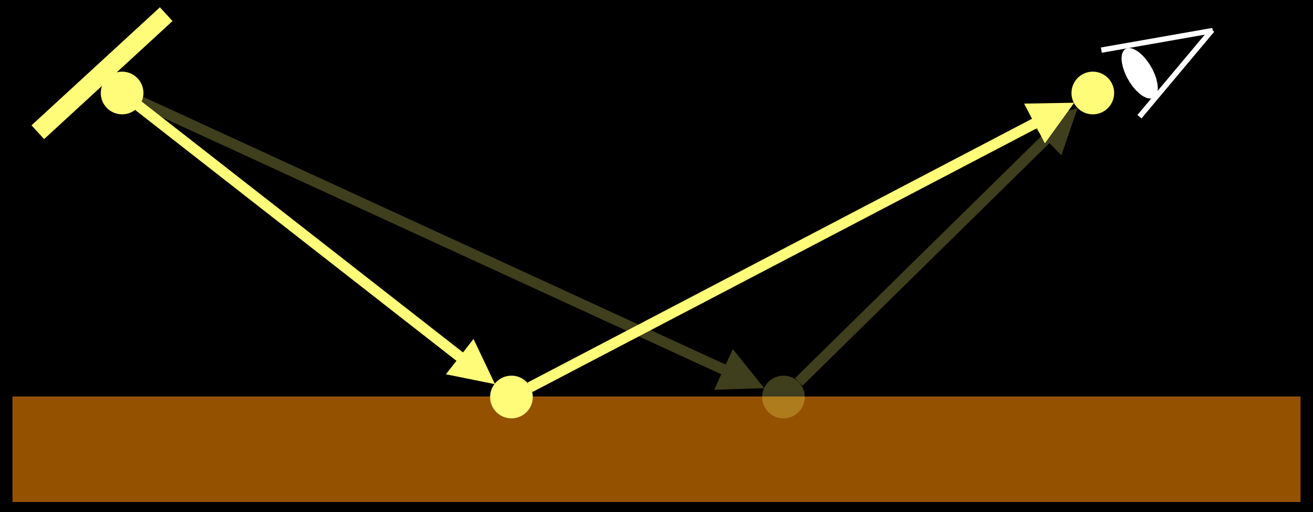

Multiplexed primary sample space

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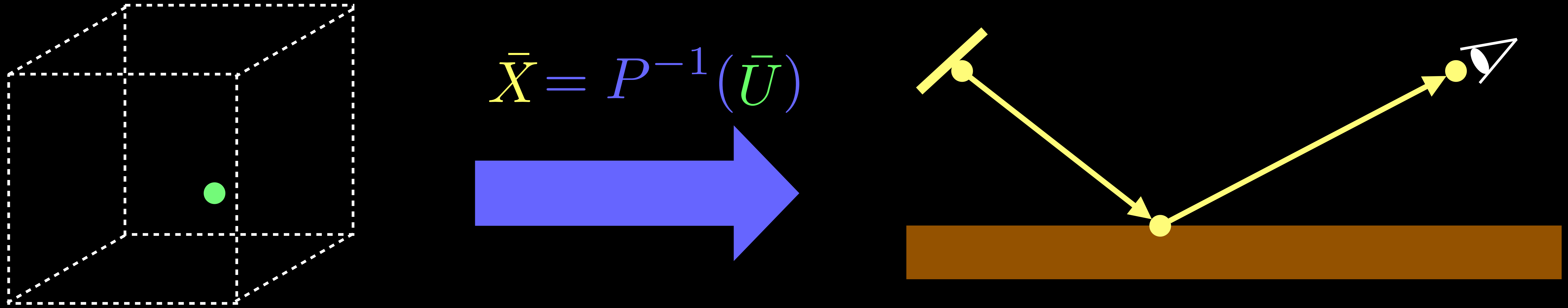

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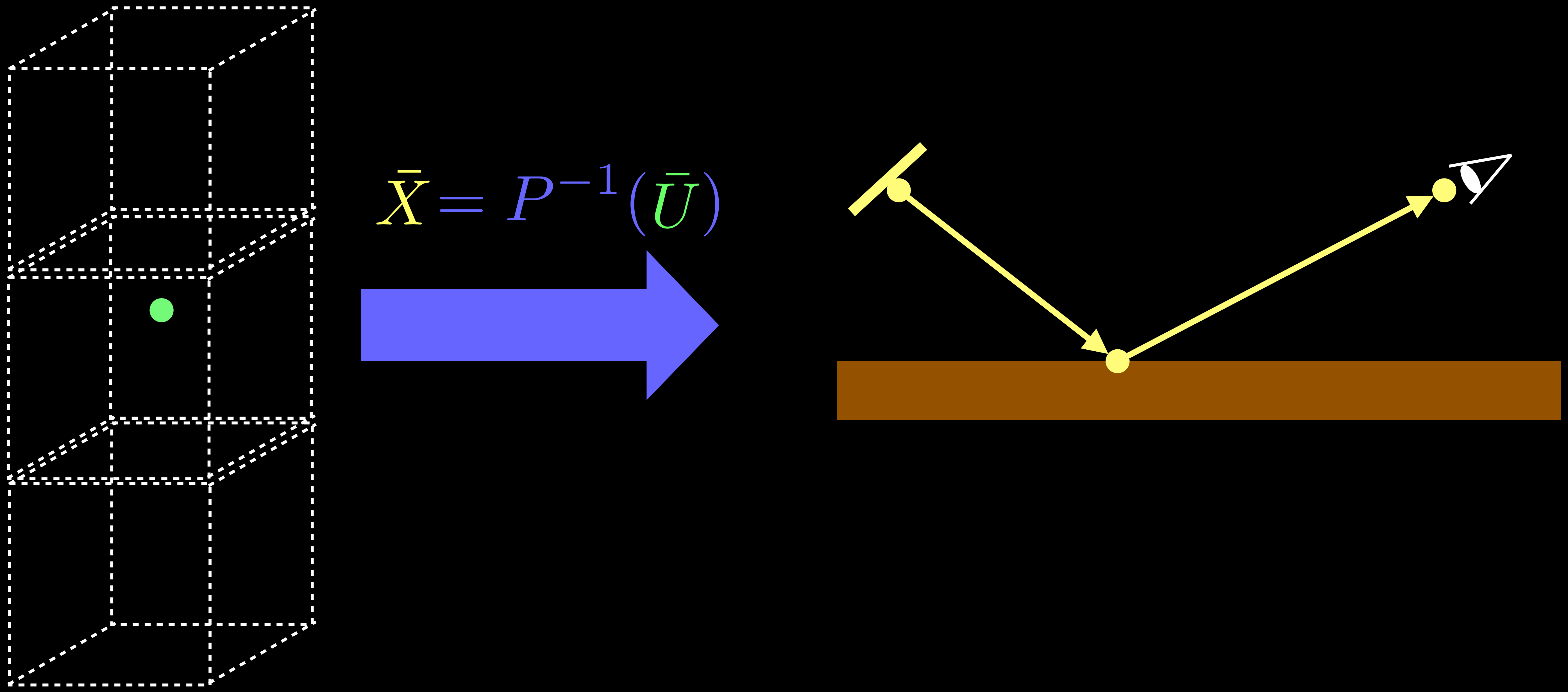
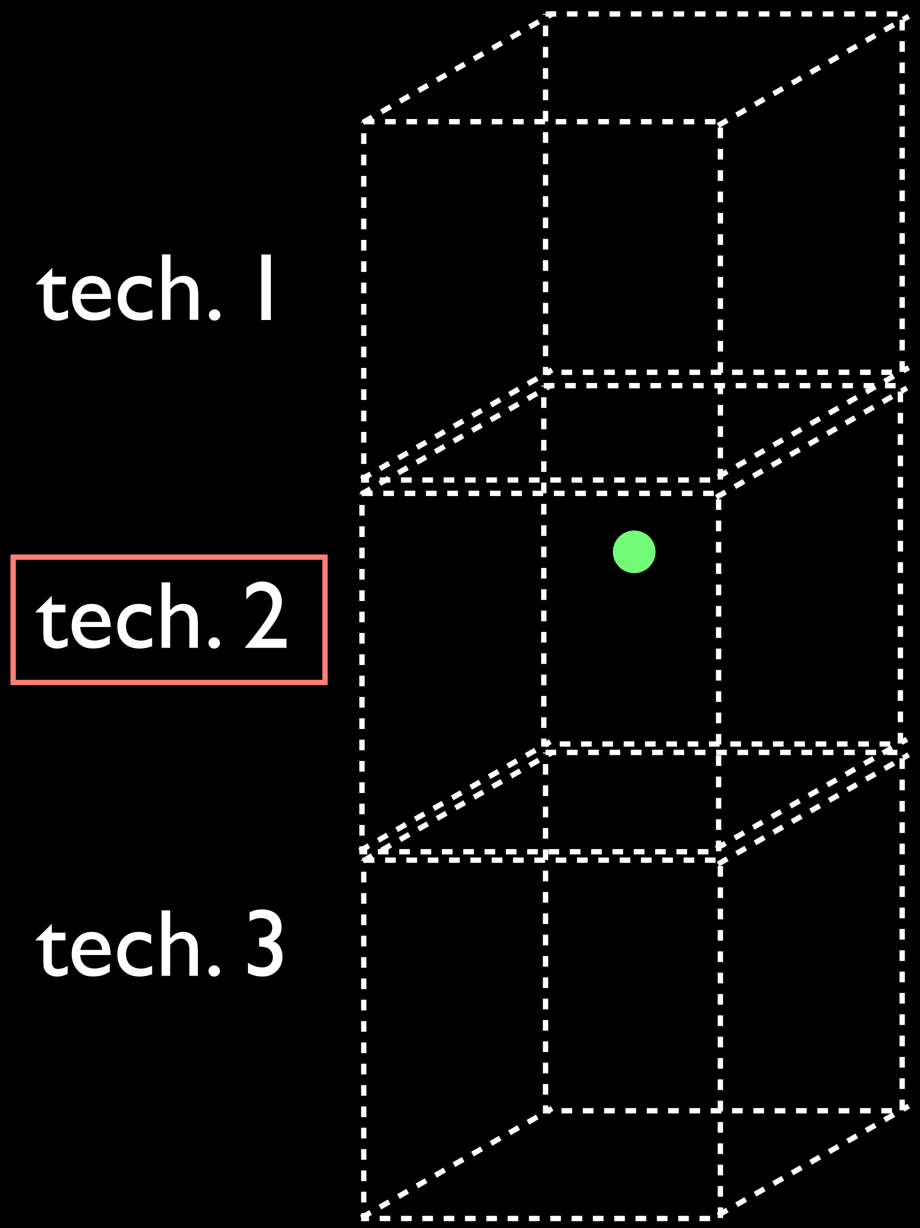
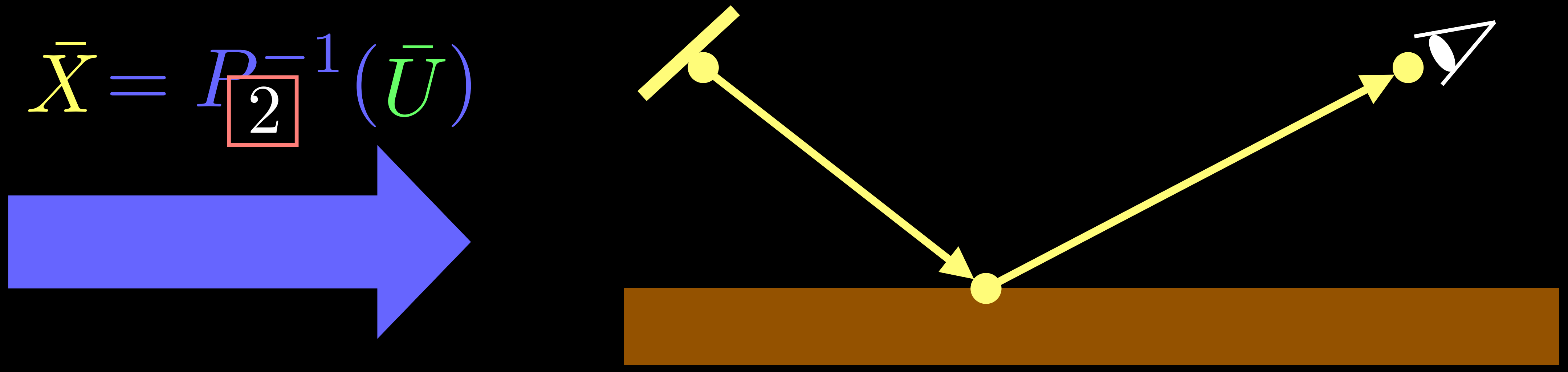


$$\bar{X} = P^{-1}(\bar{U})$$

Multiplexed primary sample space



$$\bar{X} = P_{\boxed{2}}^{-1}(\bar{U})$$



Multiplexed primary sample space

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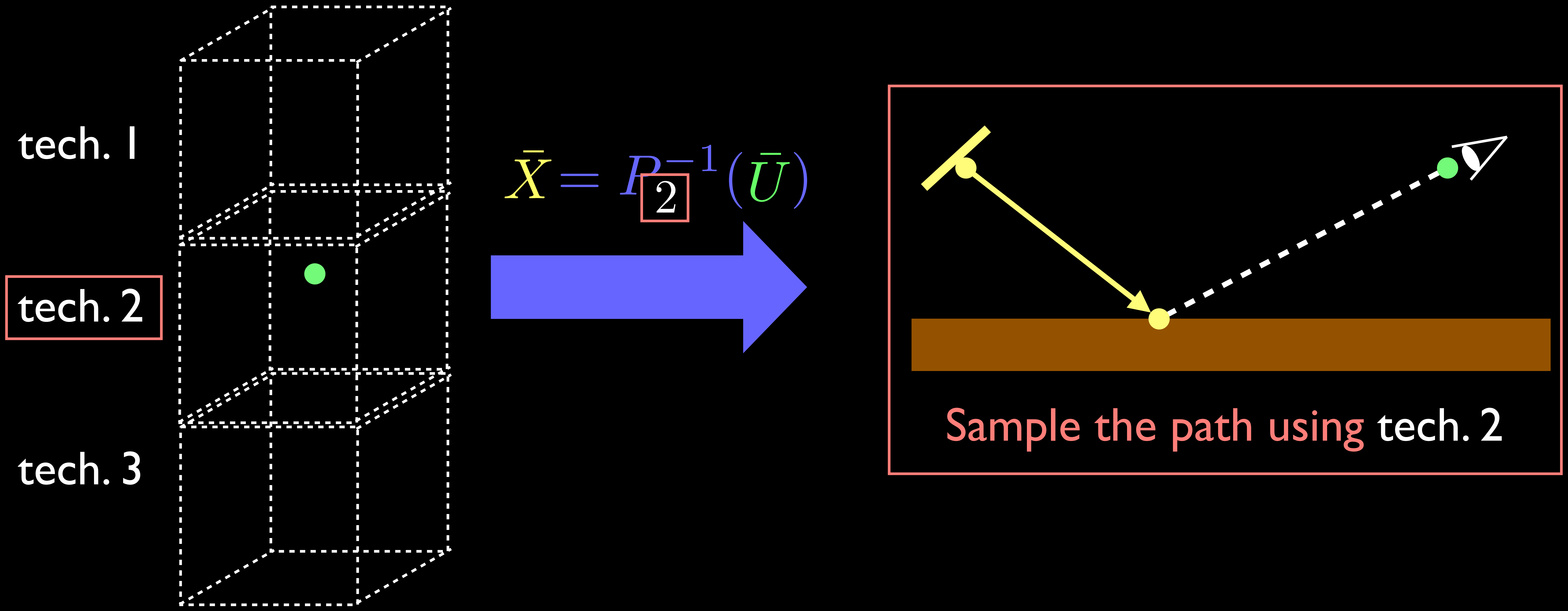
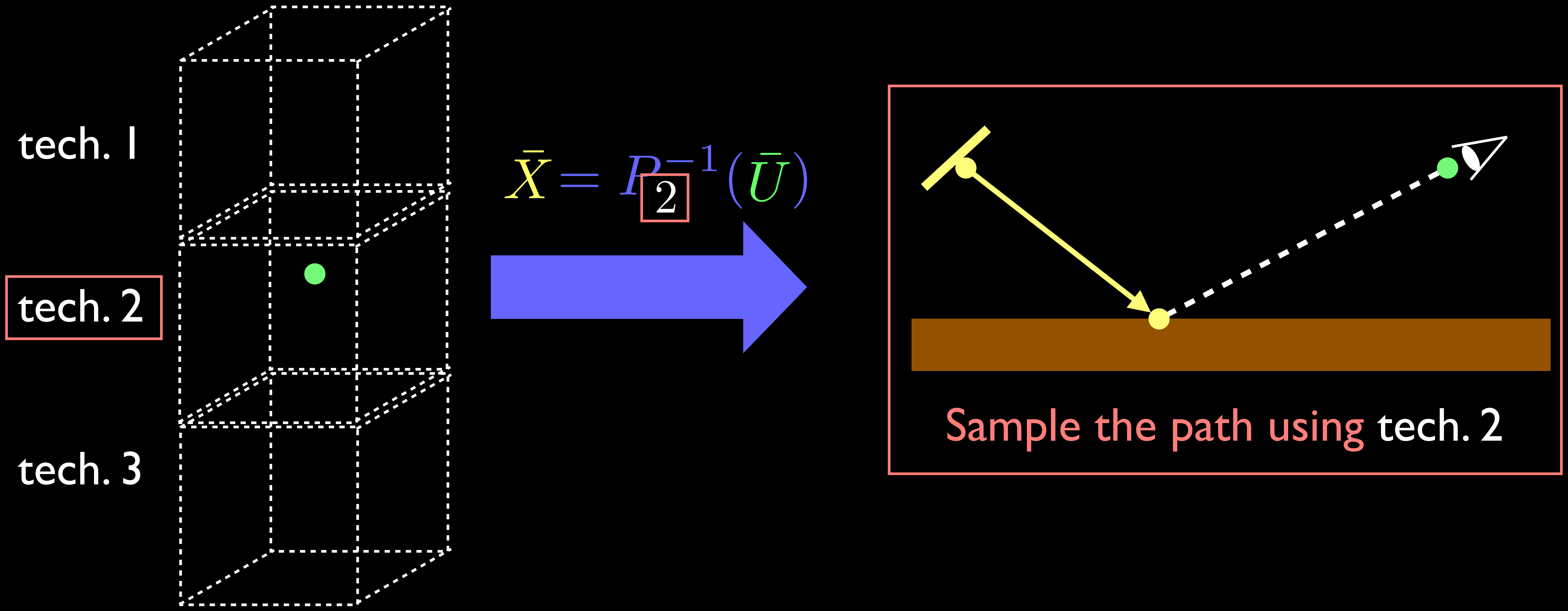


Multiplexed primary sample space

Extension of the primary sample space by technique index



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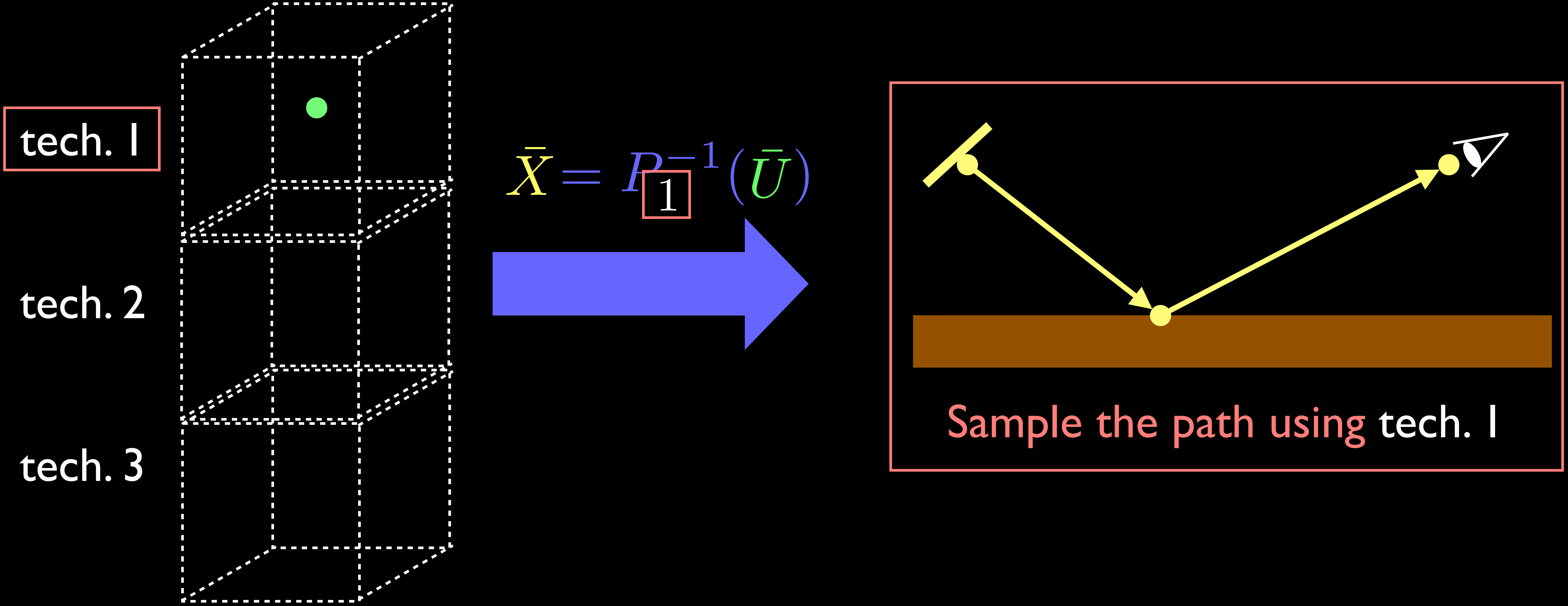
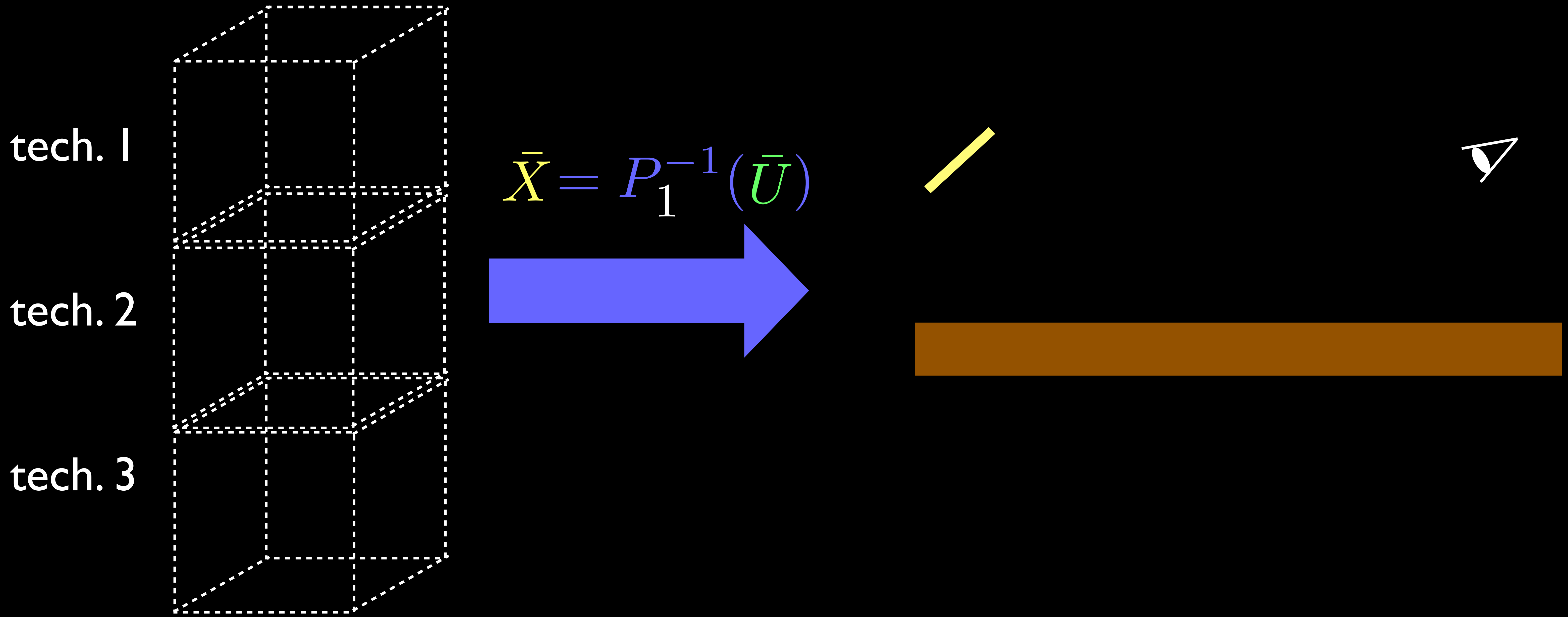


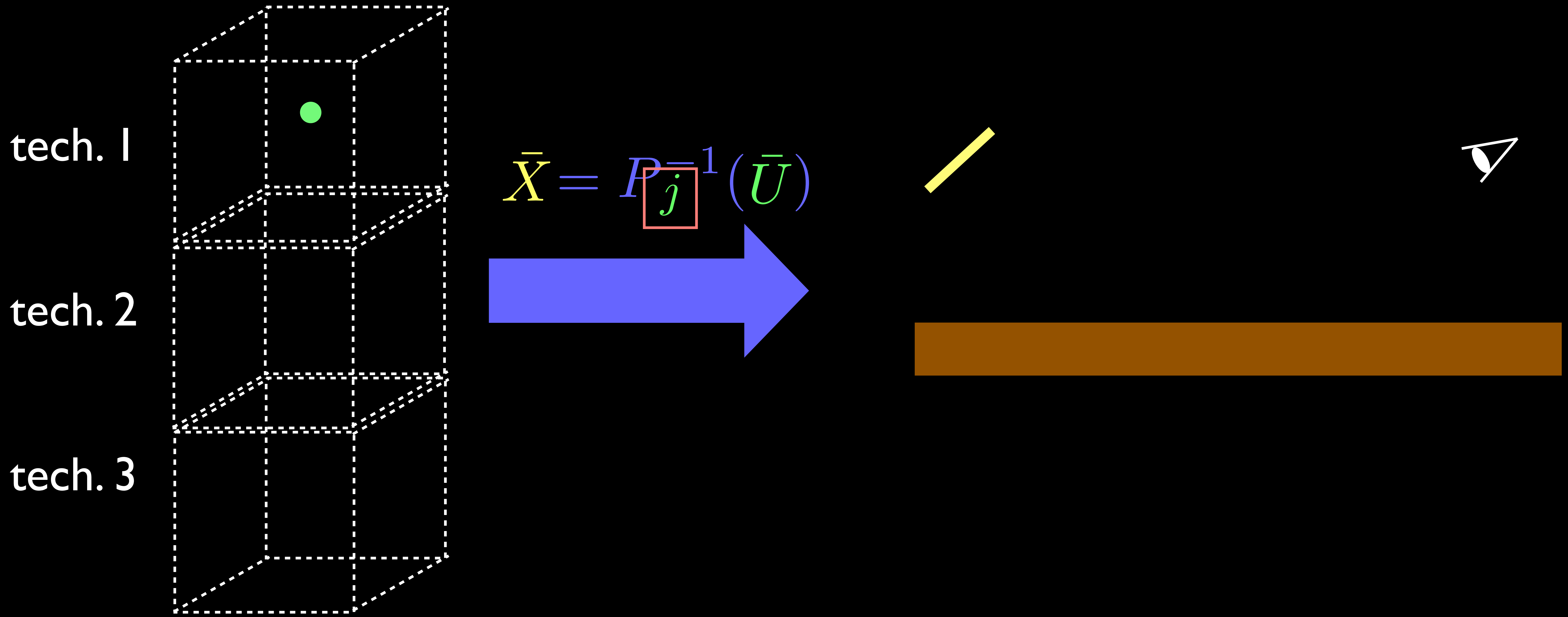
Multiplexed MLT

Markov chain states: $(\bar{U})$



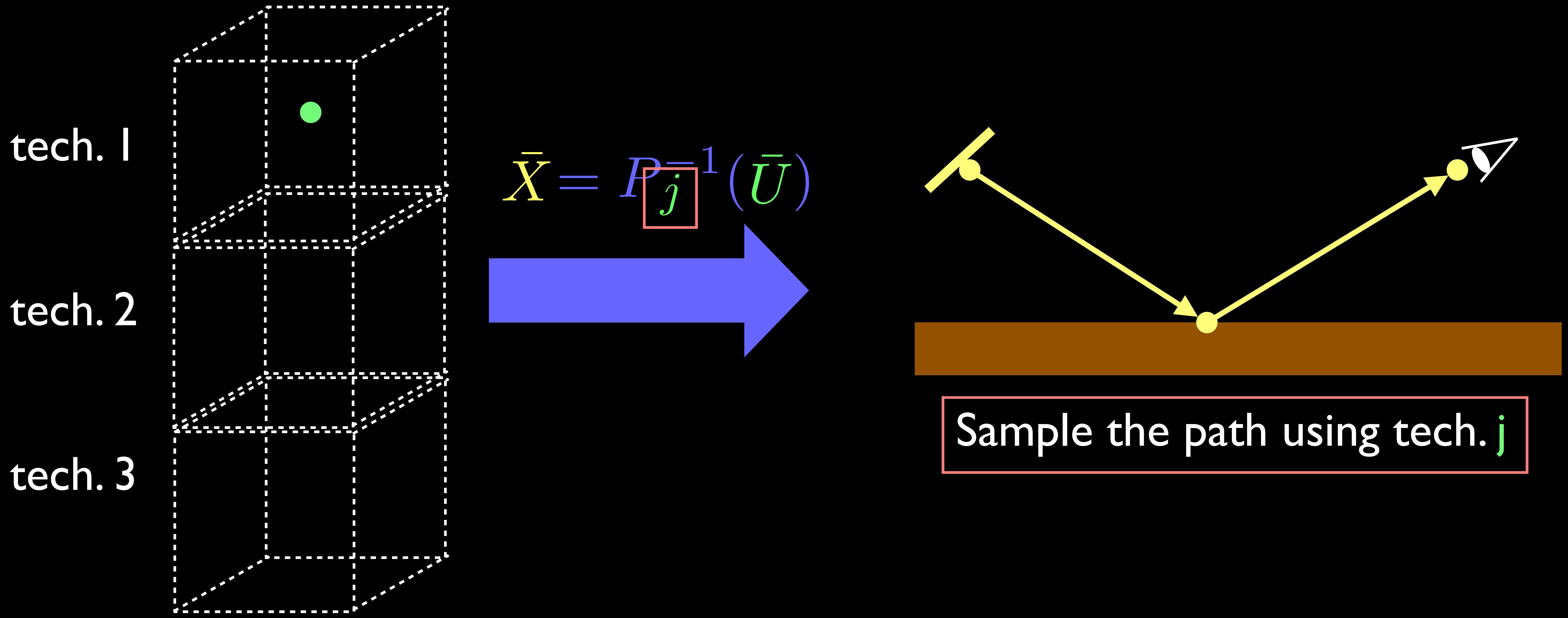
Multiplexed MLT

Markov chain states: $(\bar{U}, j)$



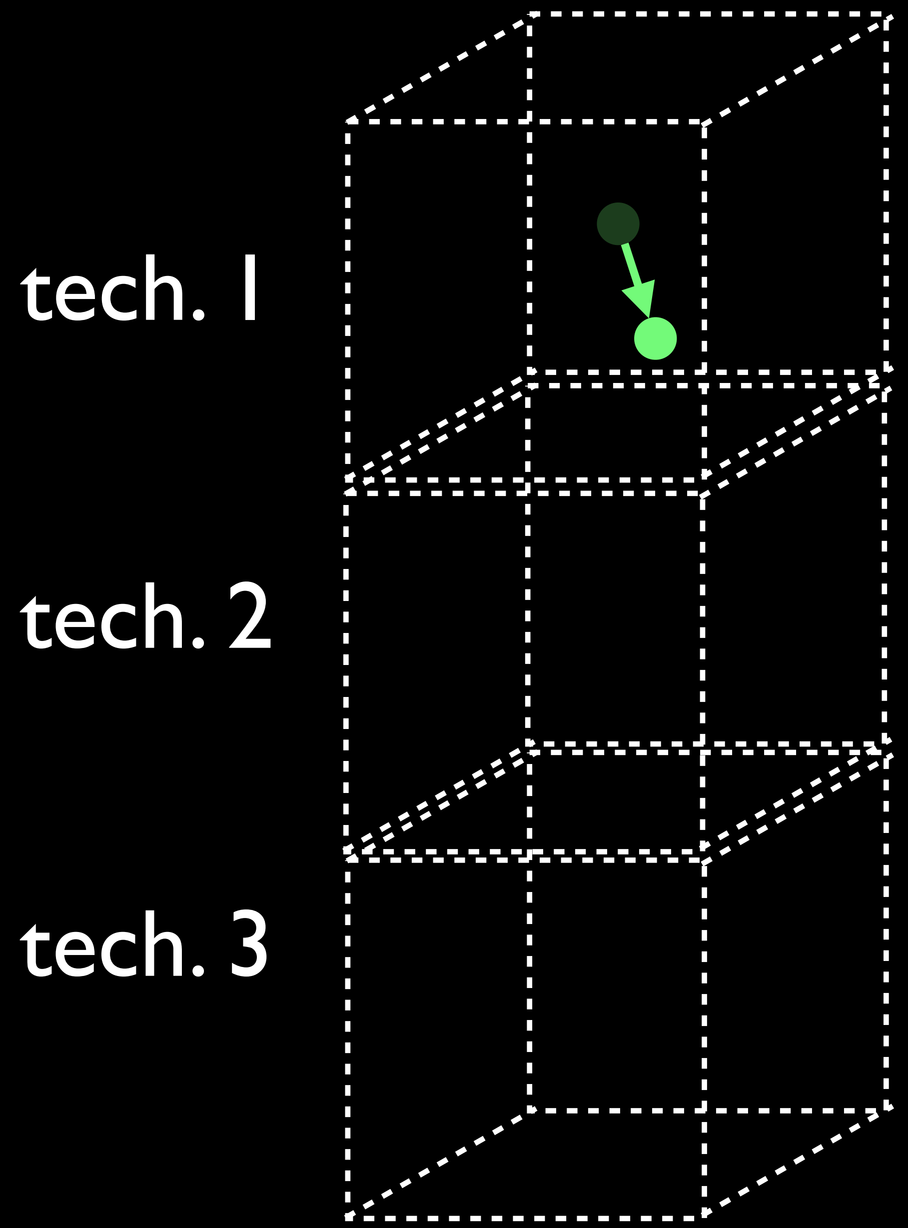
Multiplexed MLT

Markov chain states: $(\bar{U}, j)$

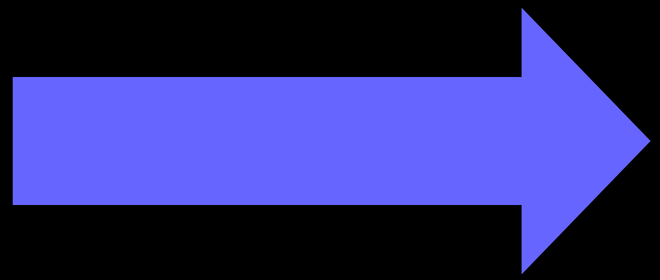


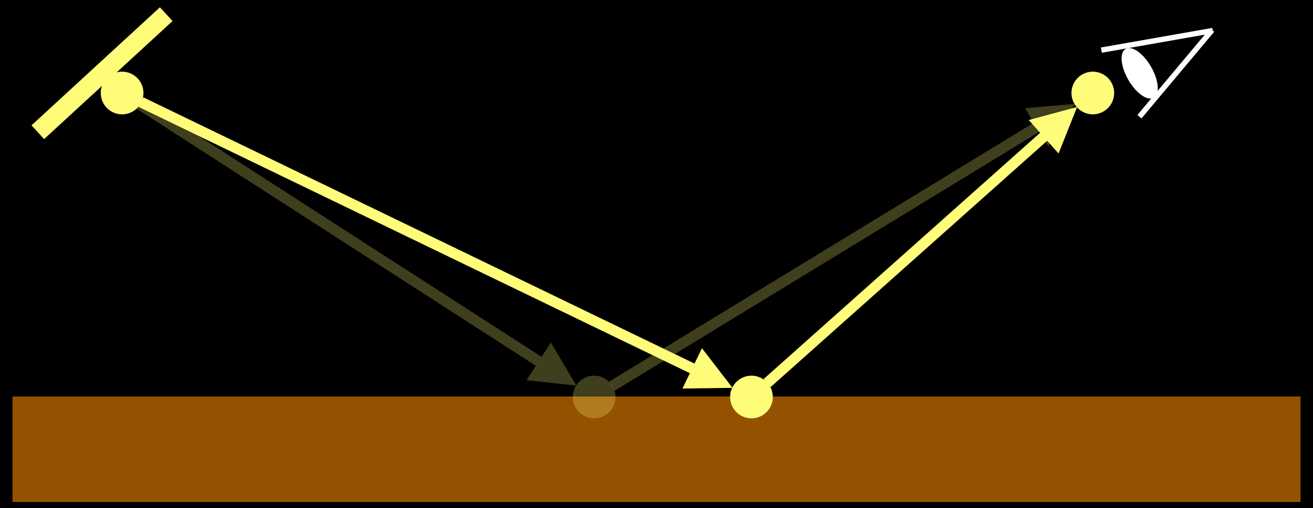
Multiplexed MLT

Markov chain states: $(\bar{U}, j)$



$$\bar{X} = P_j^{-1}(\bar{U})$$





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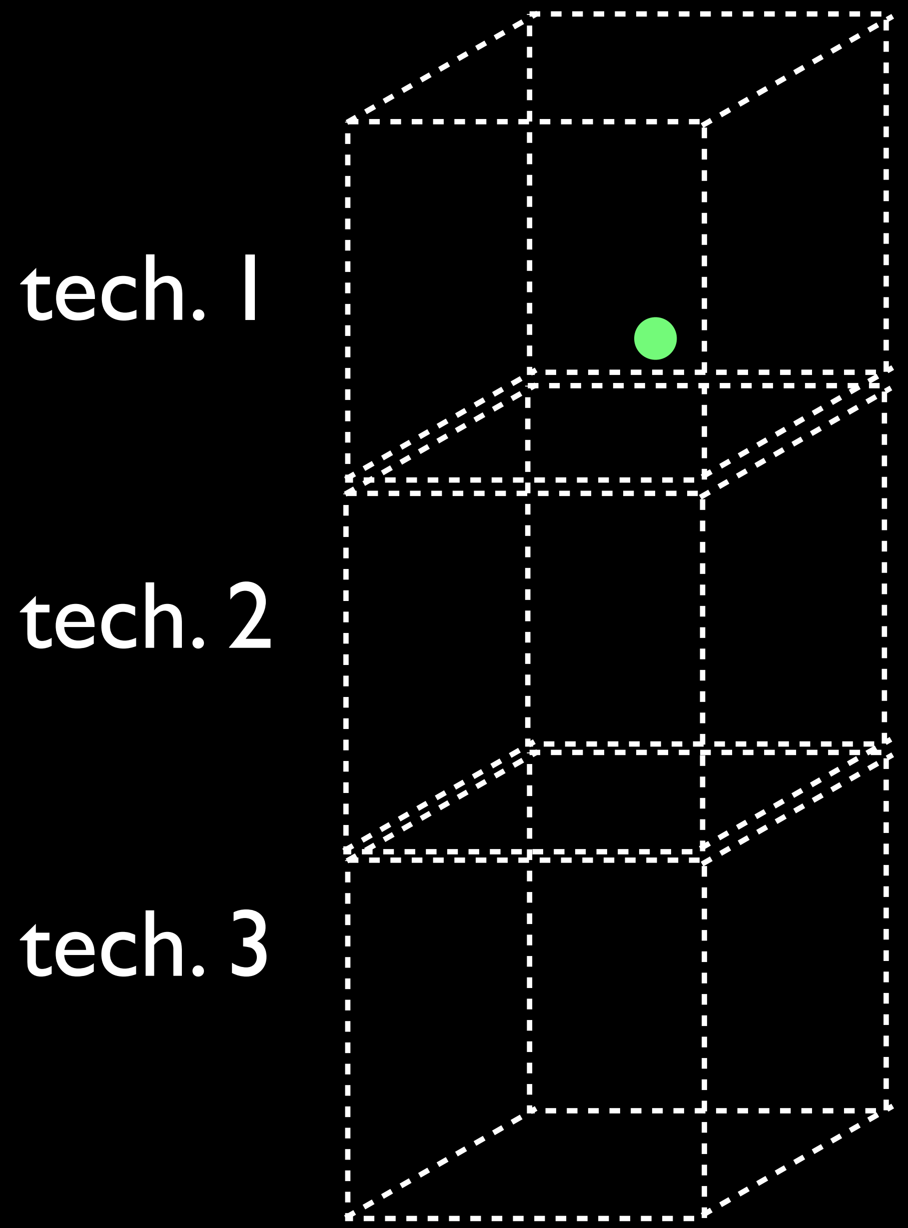

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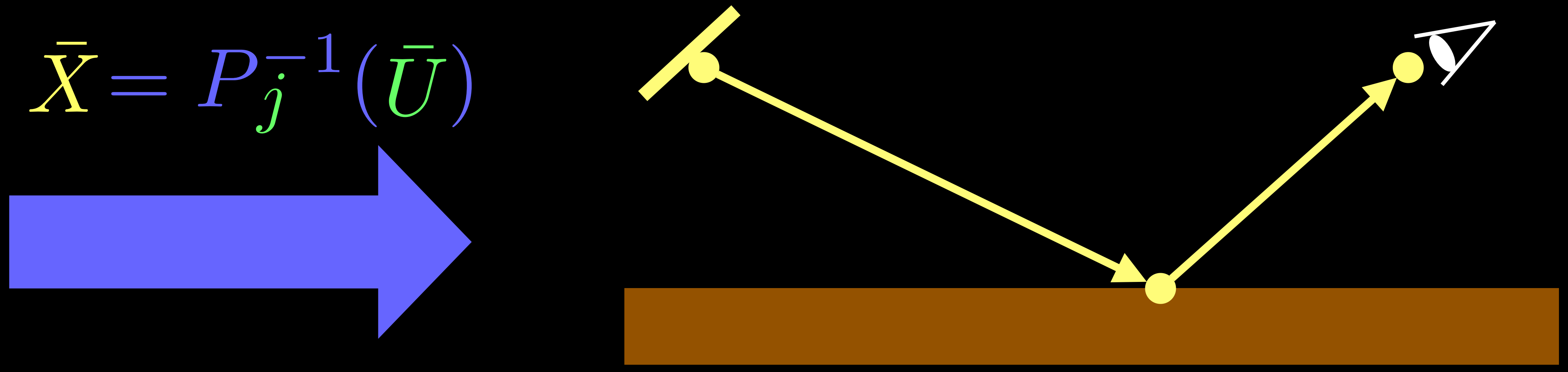

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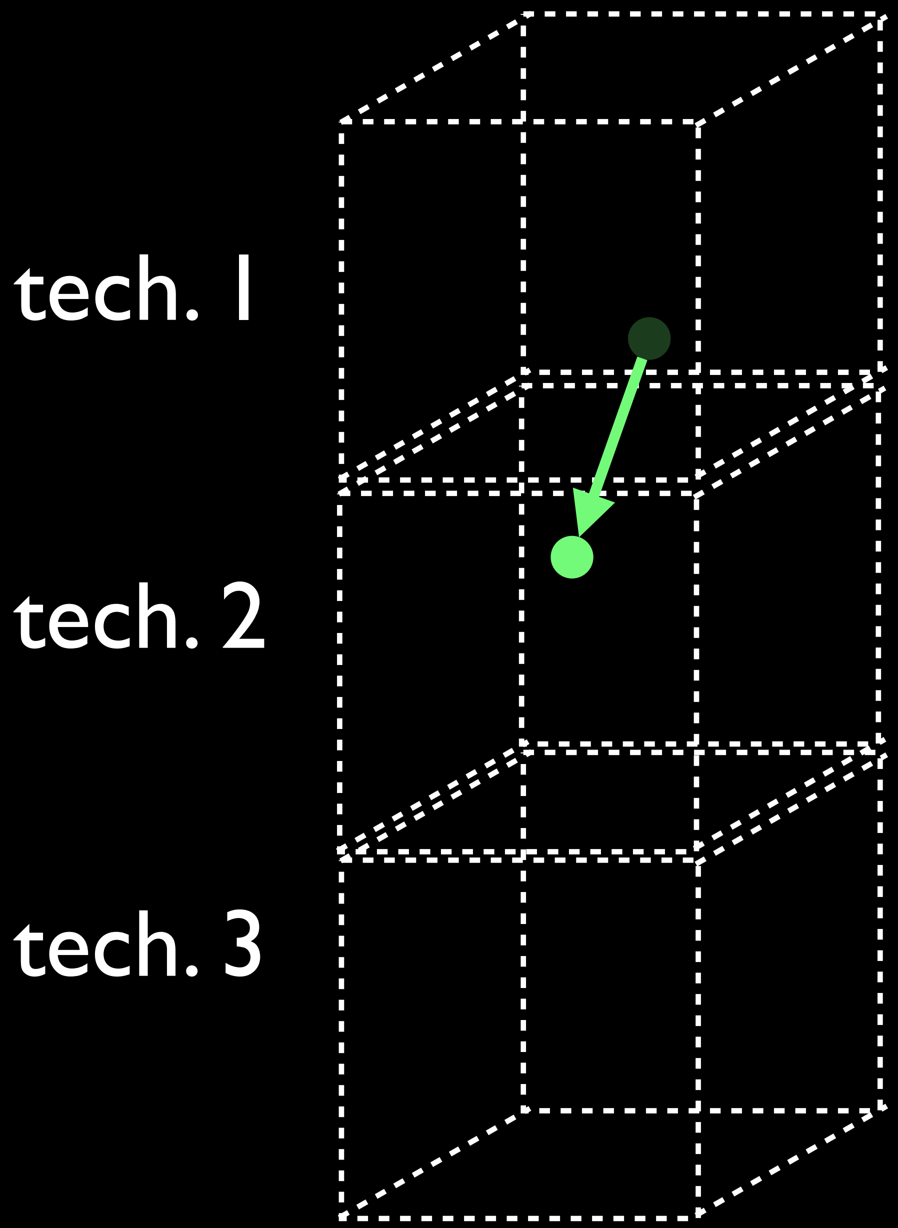
Markov chain states: $(\bar{U}, j)$



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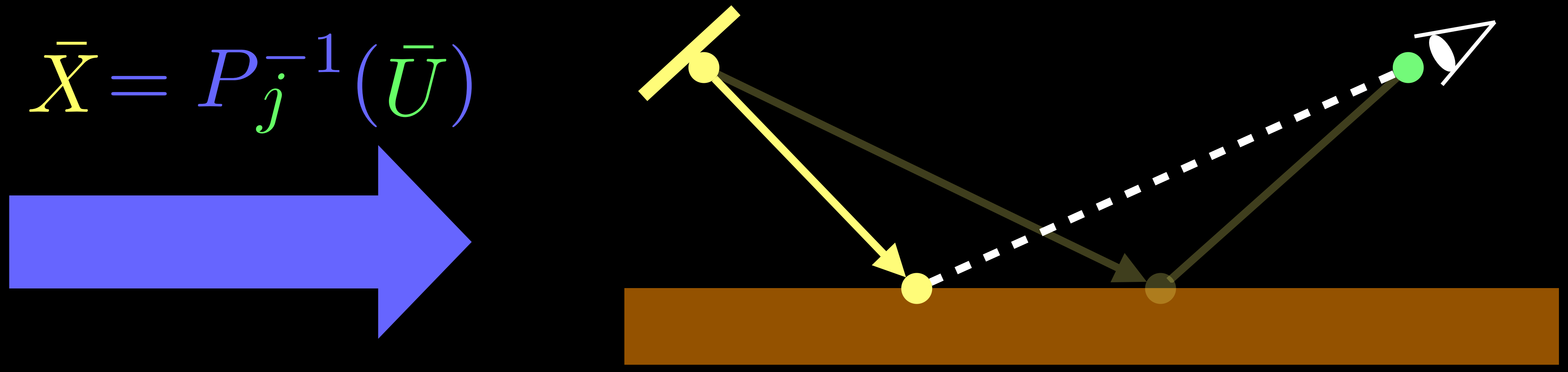
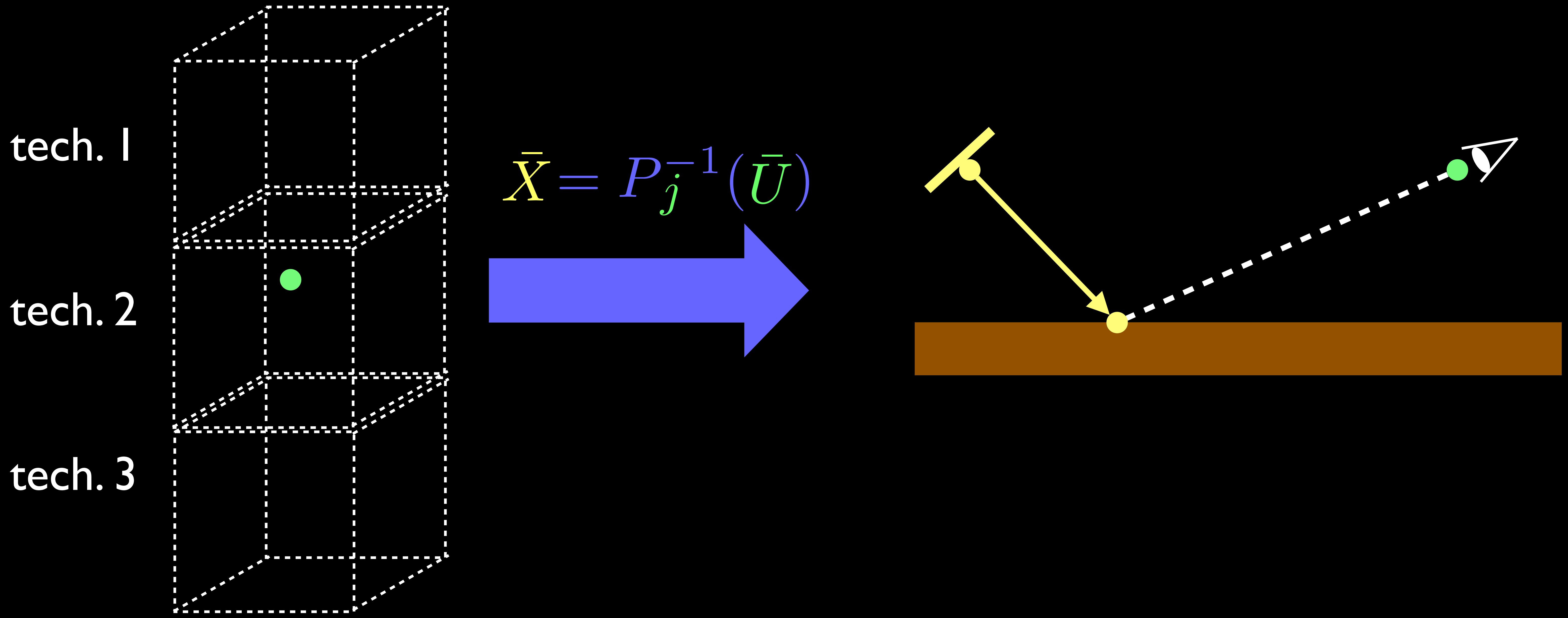


Inter-technique mutation

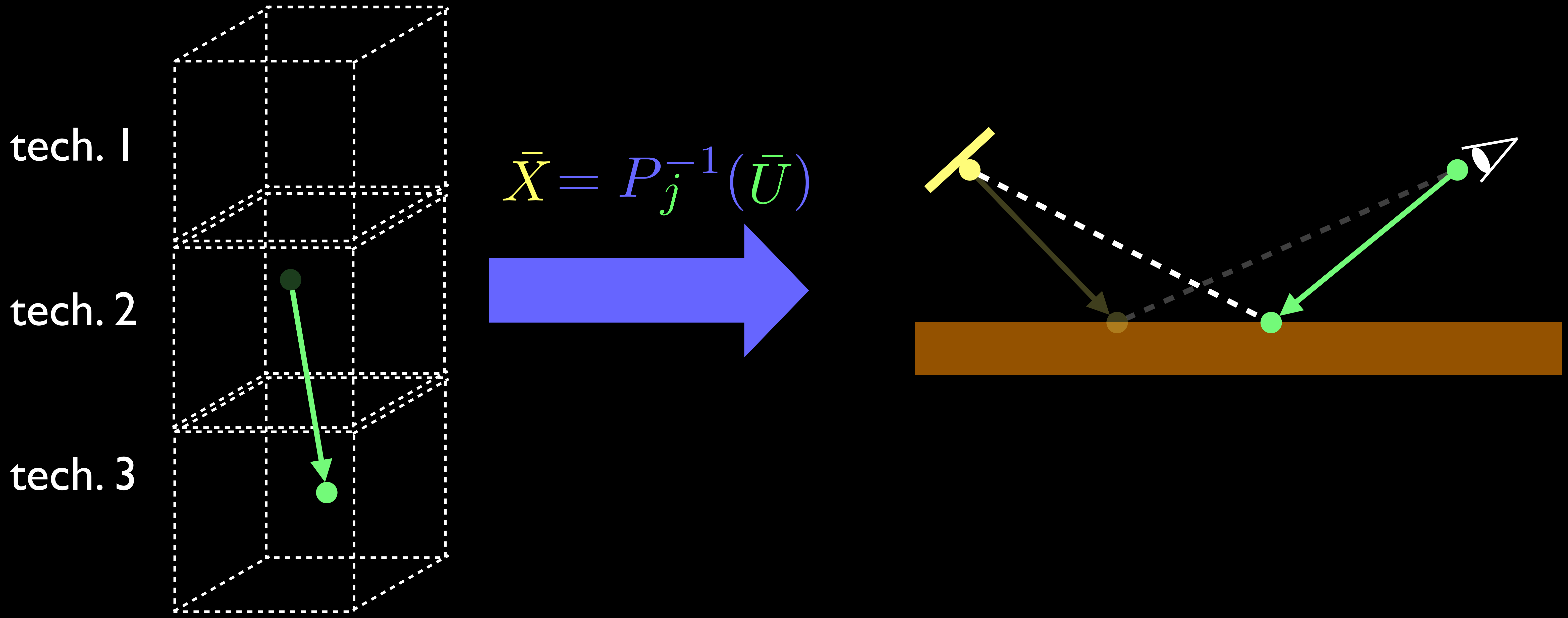
Multiplexed MLT

Markov chain states: $(\bar{U}, j)$

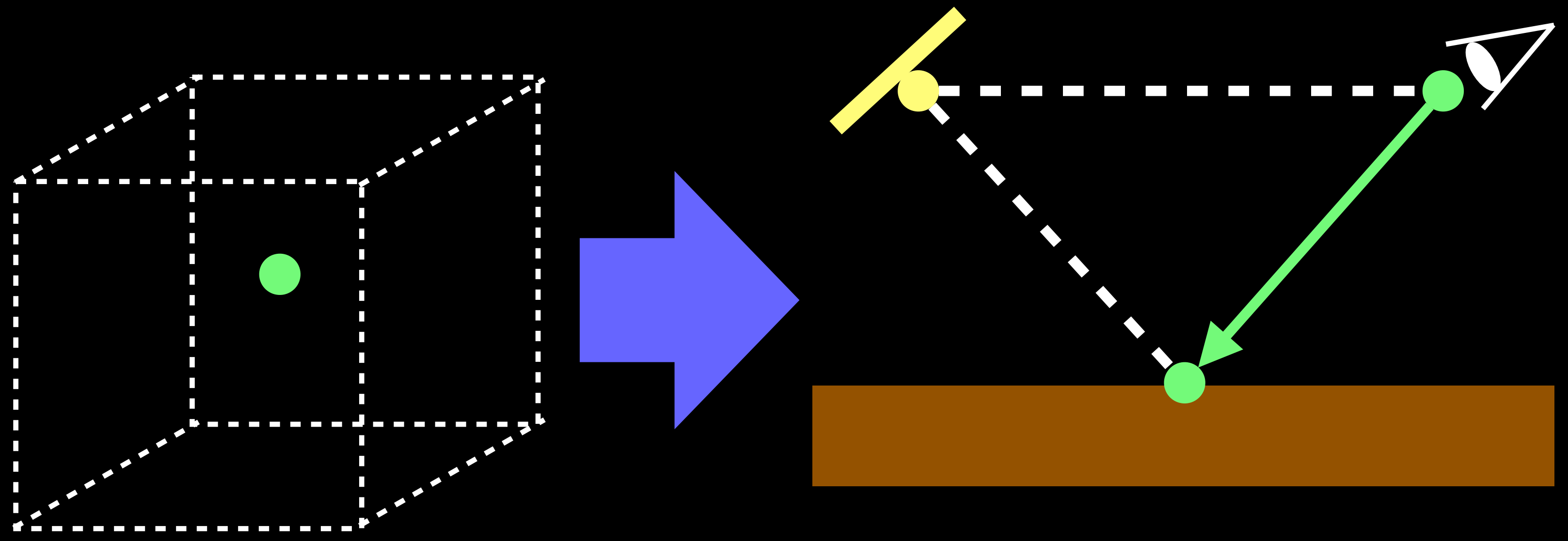


Multiplexed MLT

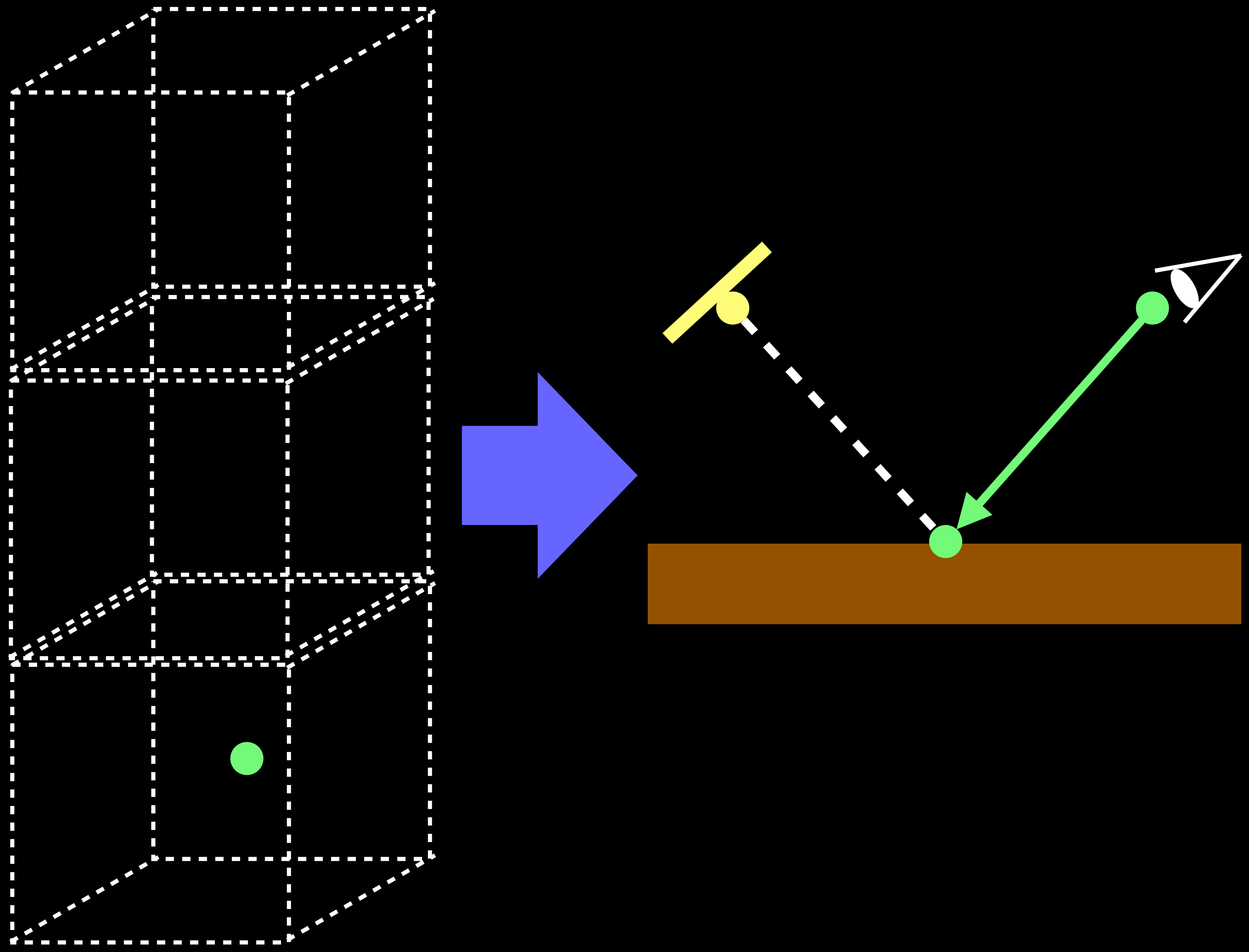
Markov chain states: $(\bar{U}, j)$



Kelemen MLT + BDPT != MMLT



Kelemen MLT + BDPT



MMLT

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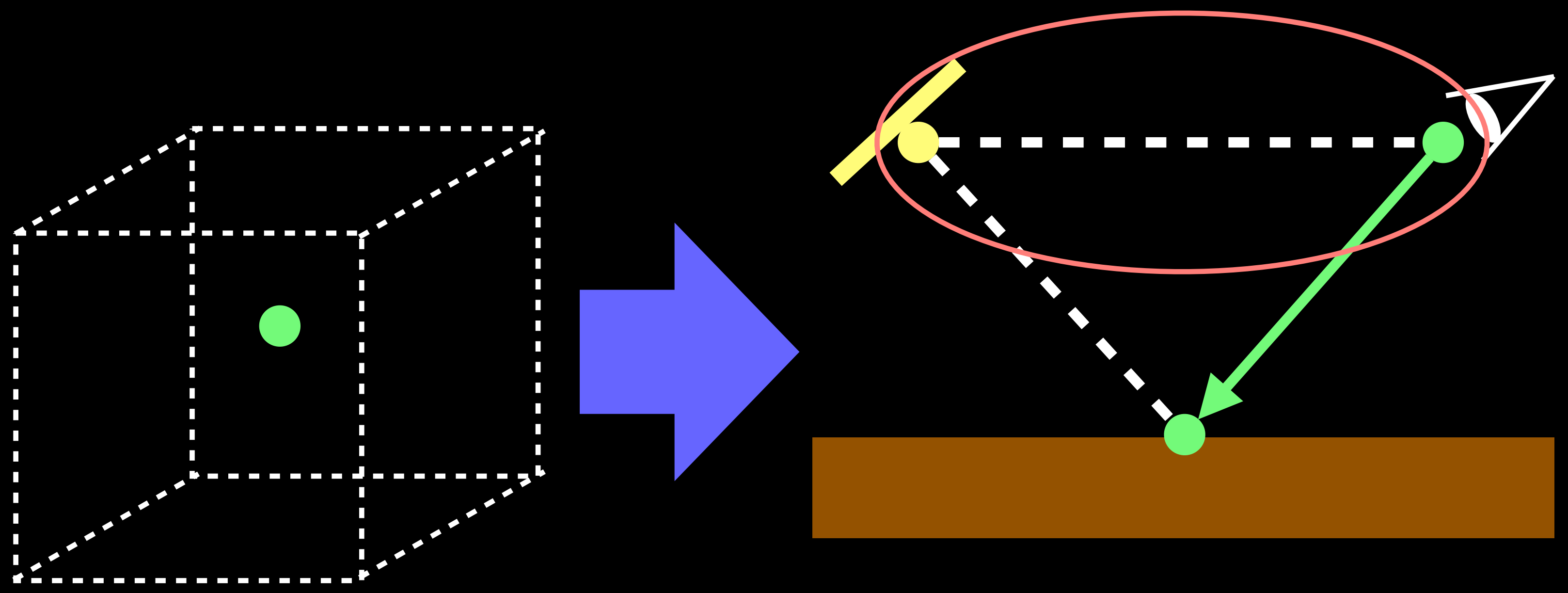
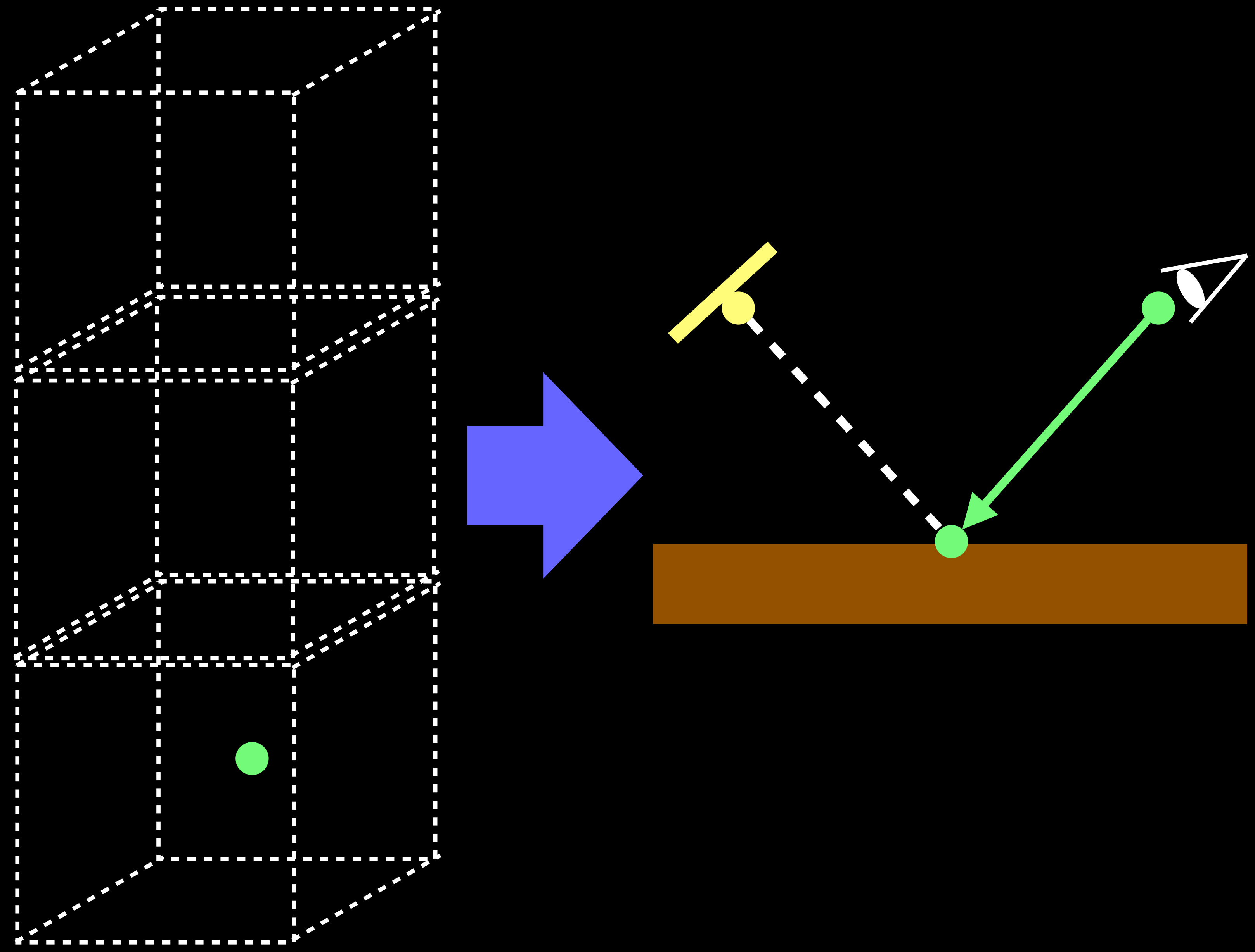


Kelemen MLT + BDPT

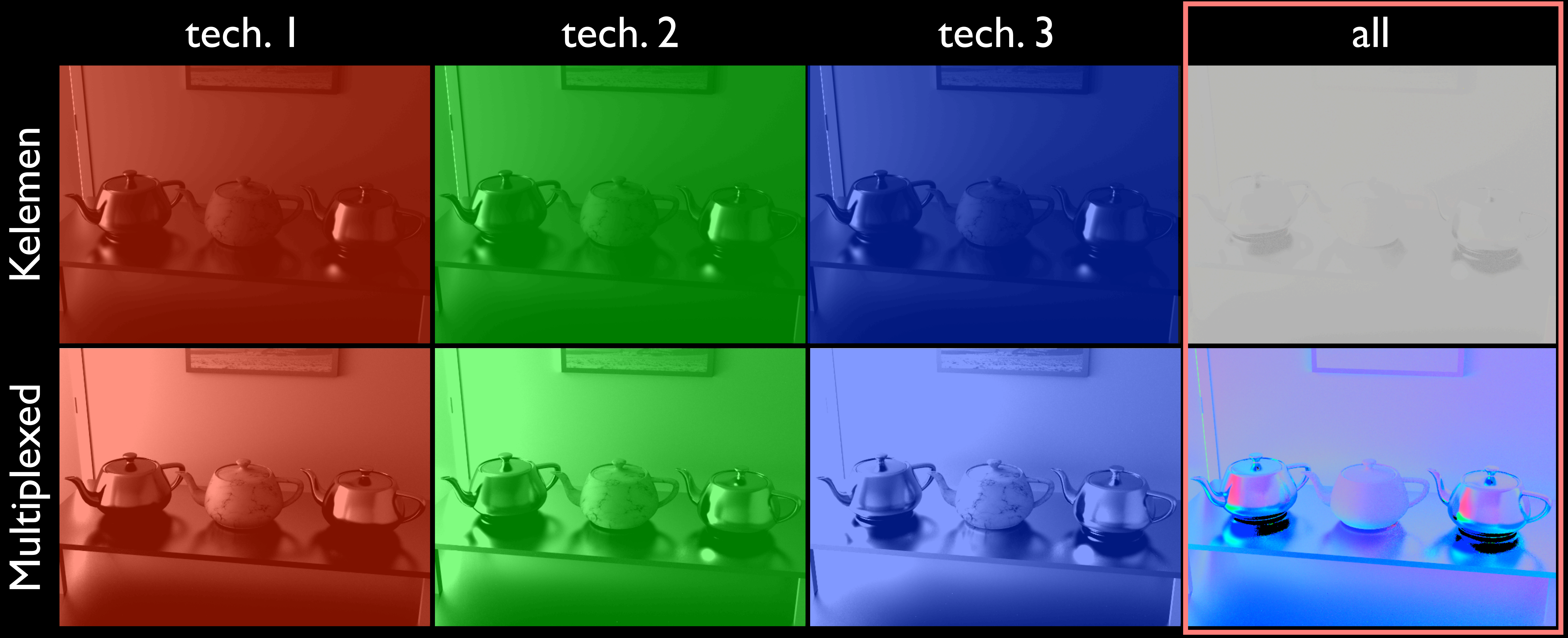
One sample = Set of BDPT connections



MMLT

One sample = One path

Kelemen MLT + BDPT != MMLT



Kelemen MLT + BDPT != MMLT

# of samples with MMLT

≈

Actual relative contributions

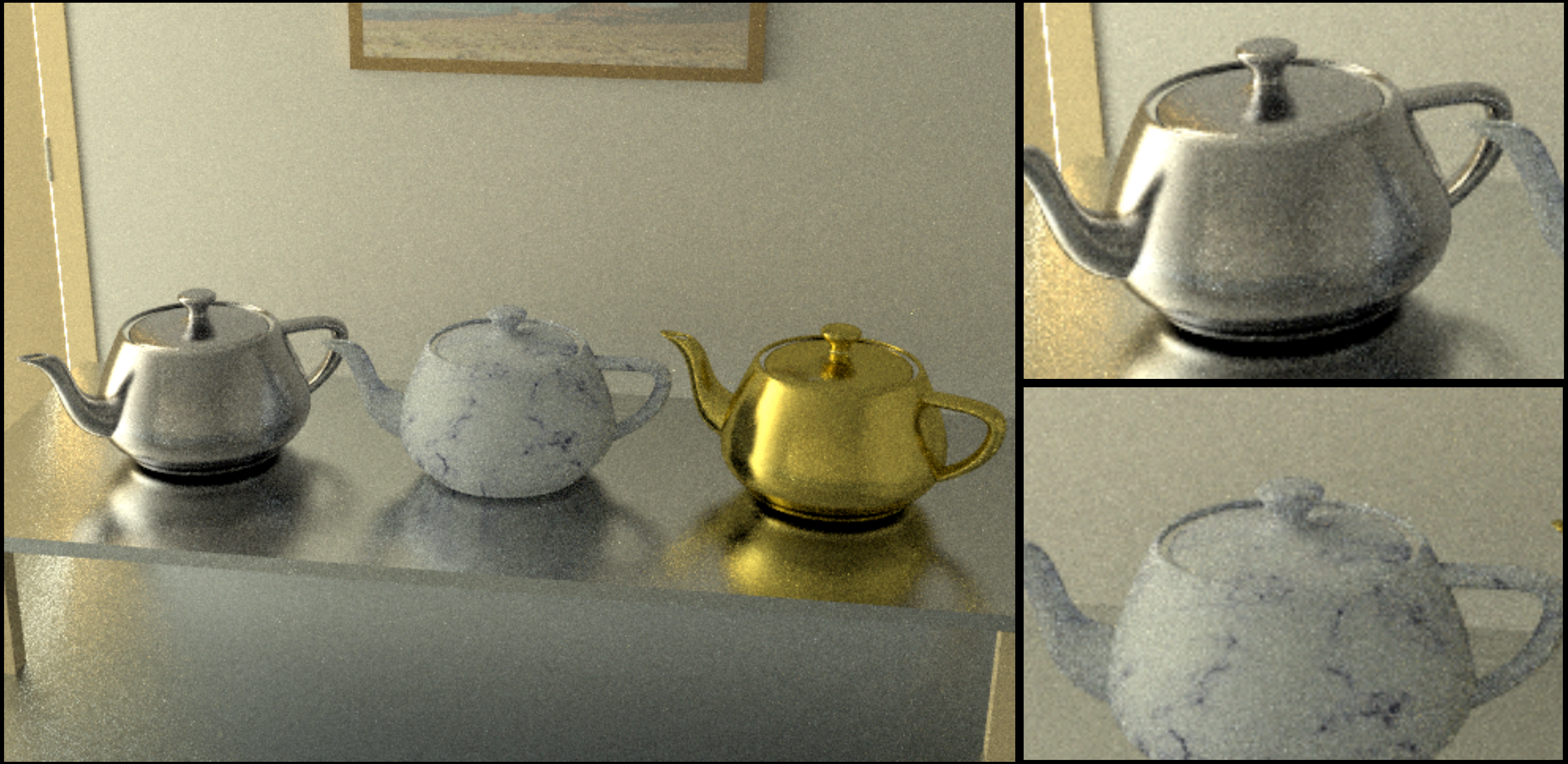
Results

Comparisons

- All the comparisons are equal-time
- Proprietary rendering system
  - BDPT, Veach MLT, Kelemen MLT, Multiplexed MLT
- Mitsuba [Jakob 10]
  - Manifold exploration

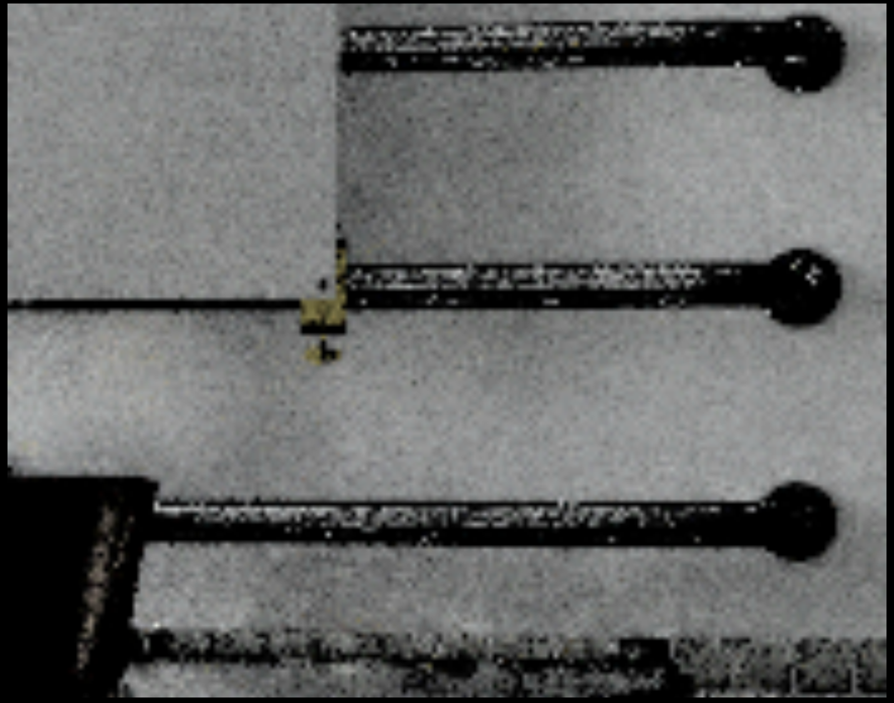
Veach MLT

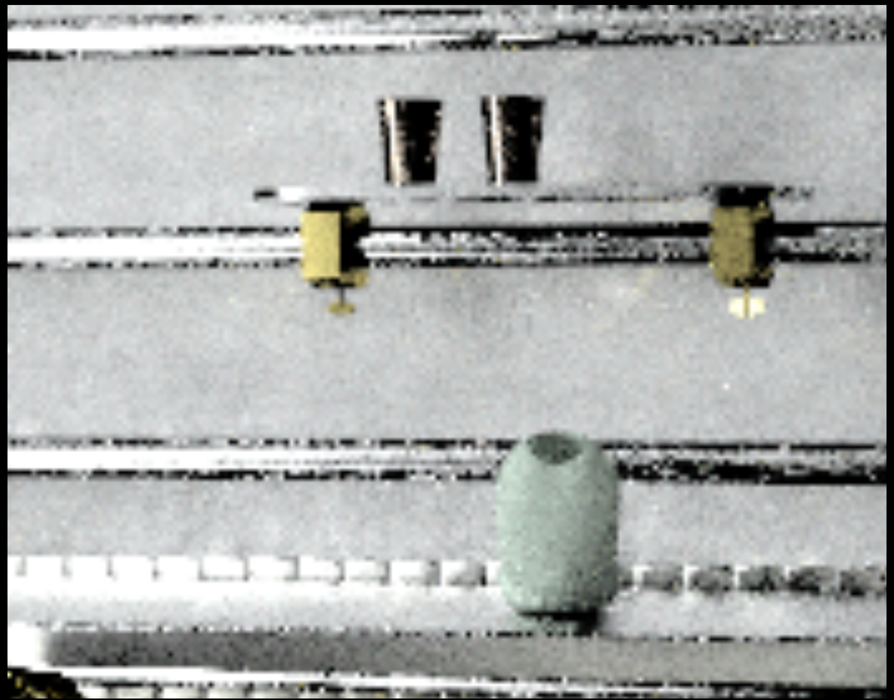
Kelemen MLT



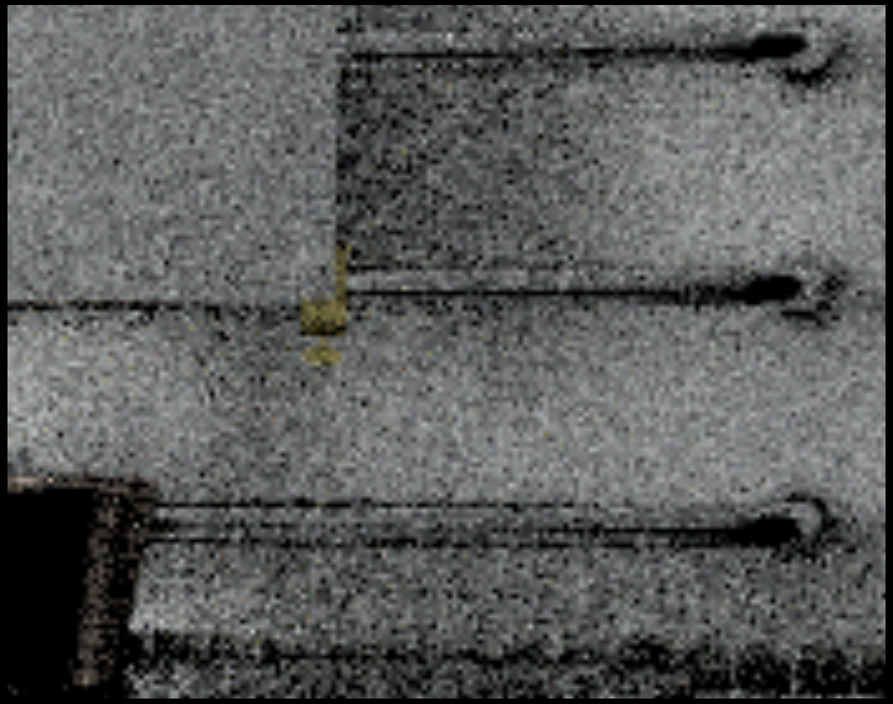
Multiplexed MLT

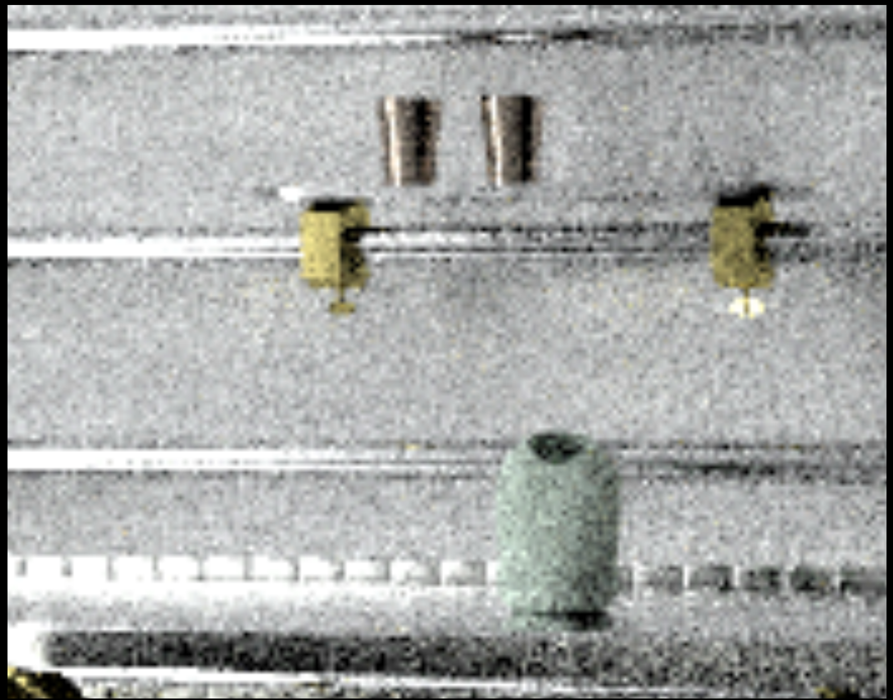
Veach MLT



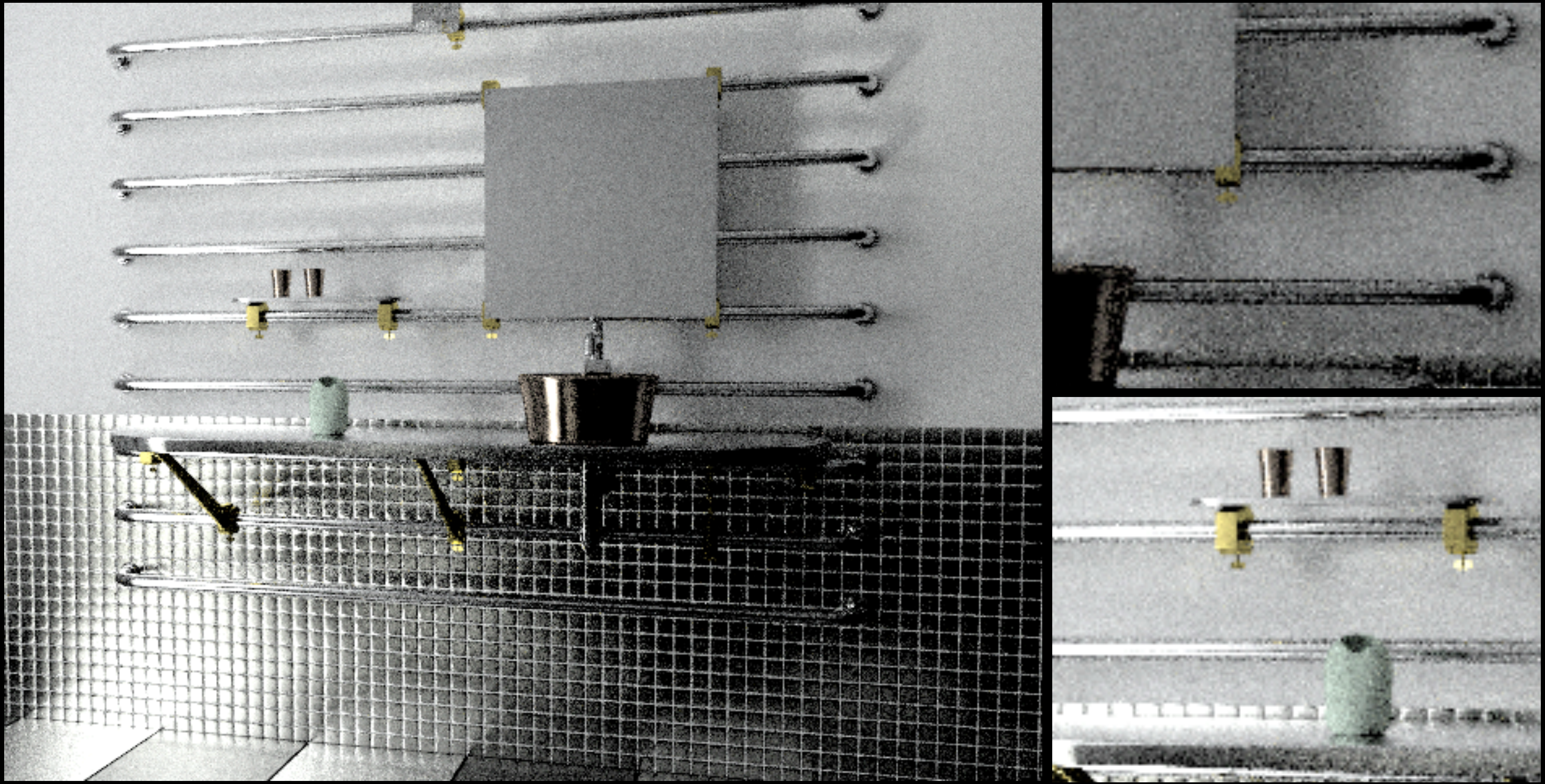


Kelemen MLT

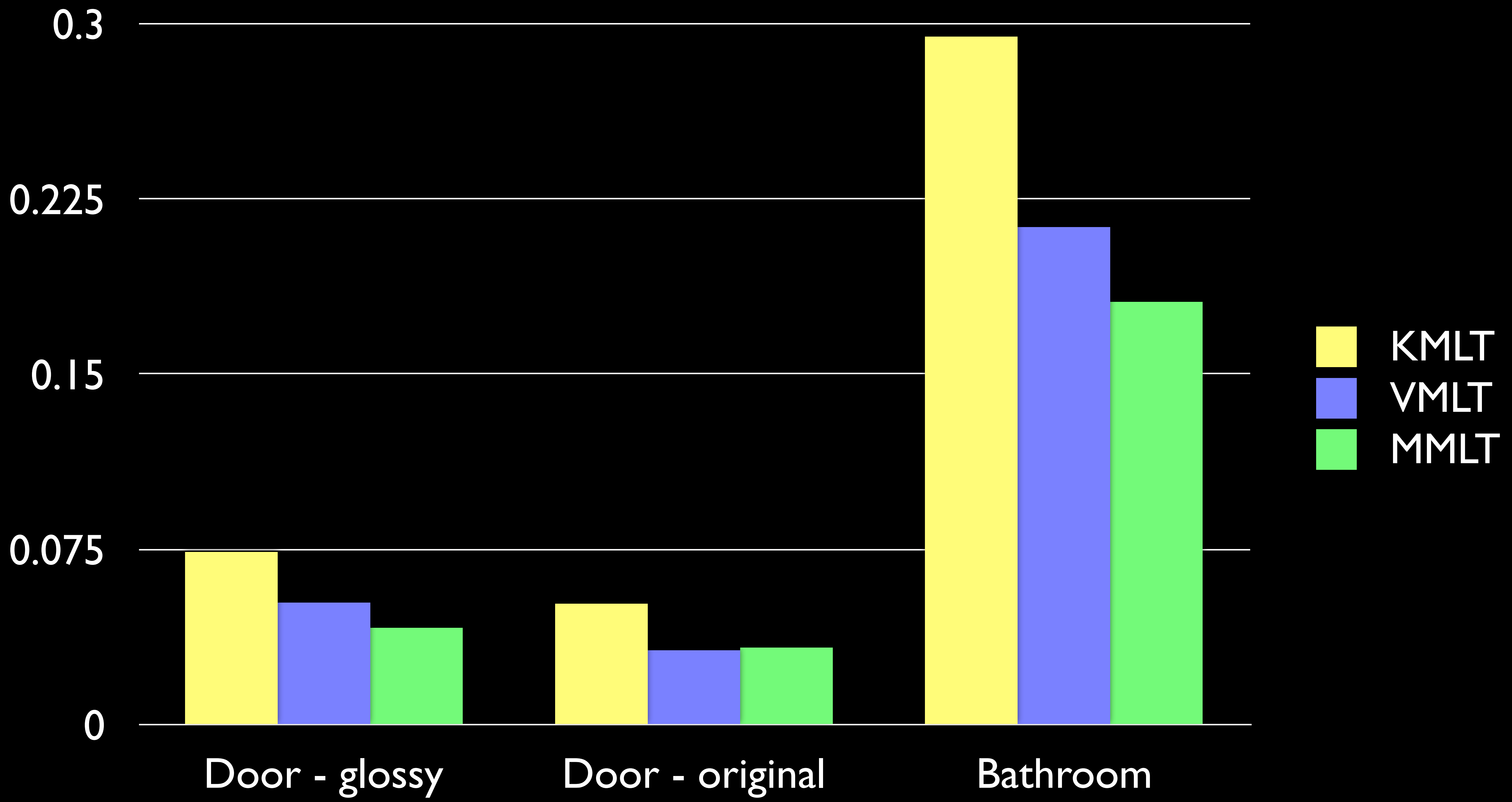




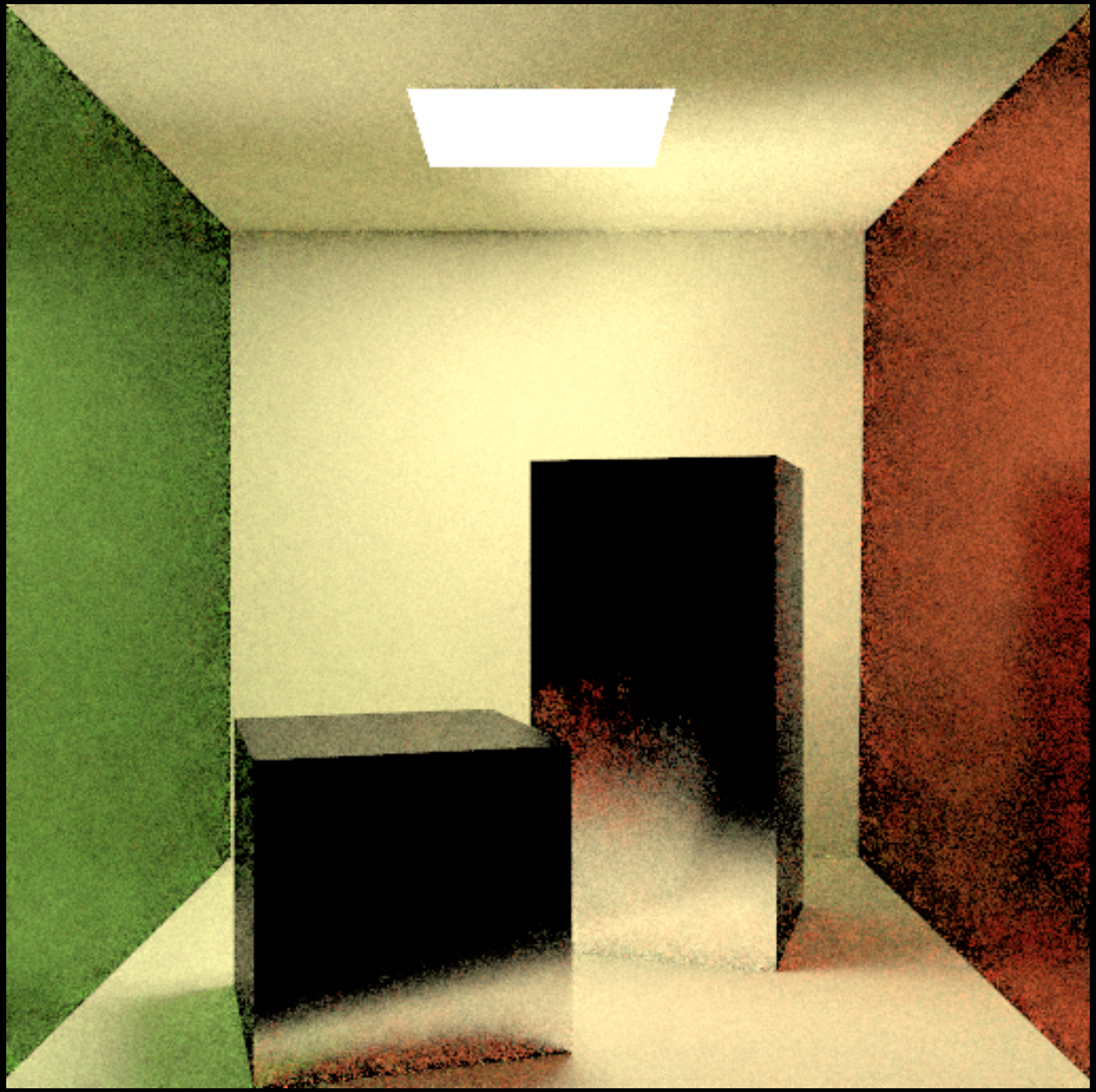
Multiplexed MLT



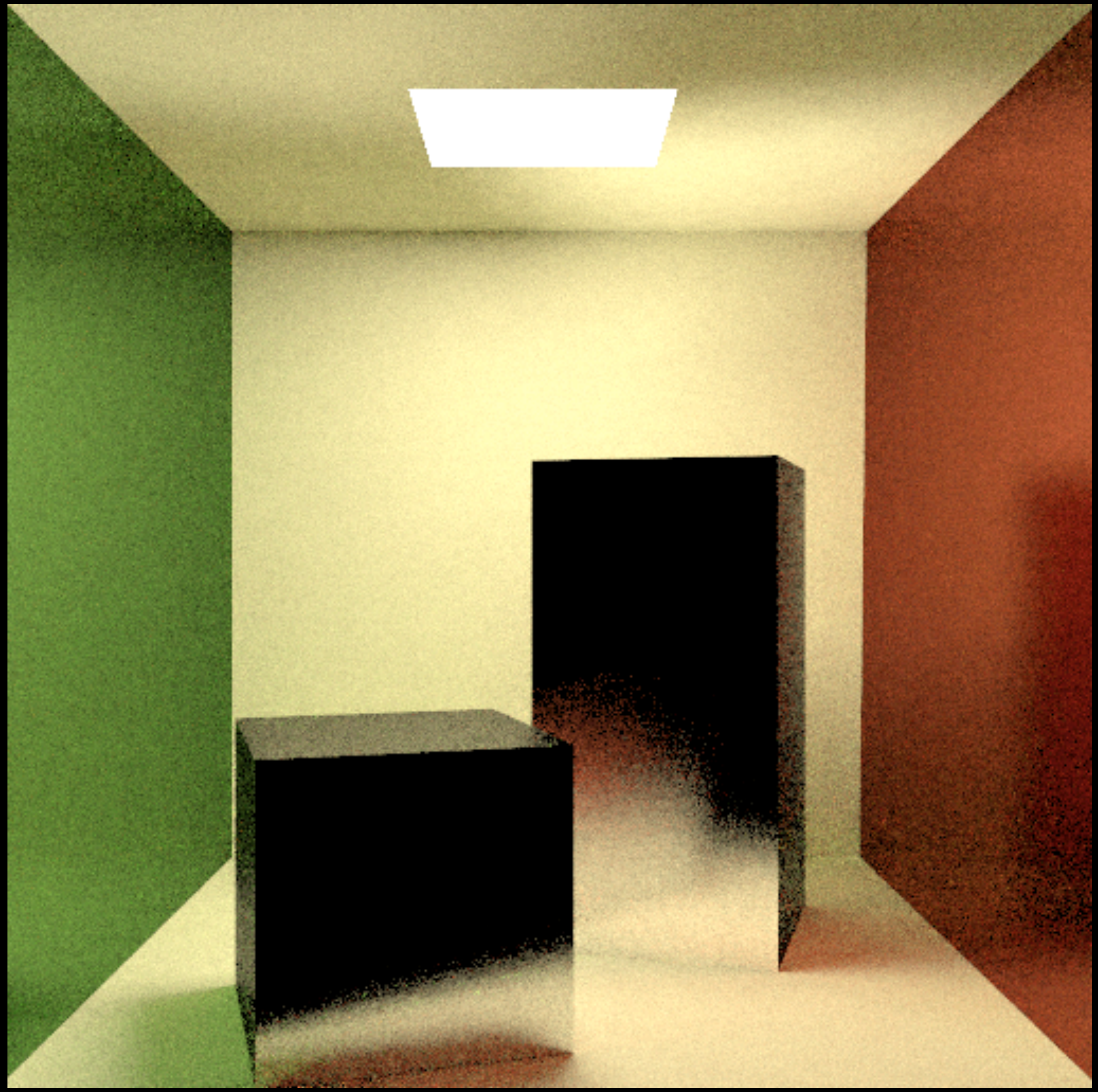
RMS errors


0.3
0.225
0.15
0.075
0
Door - glossy
Door - original
Bathroom
KMLT
VMLT
MMLT

Comparison with manifold exploration

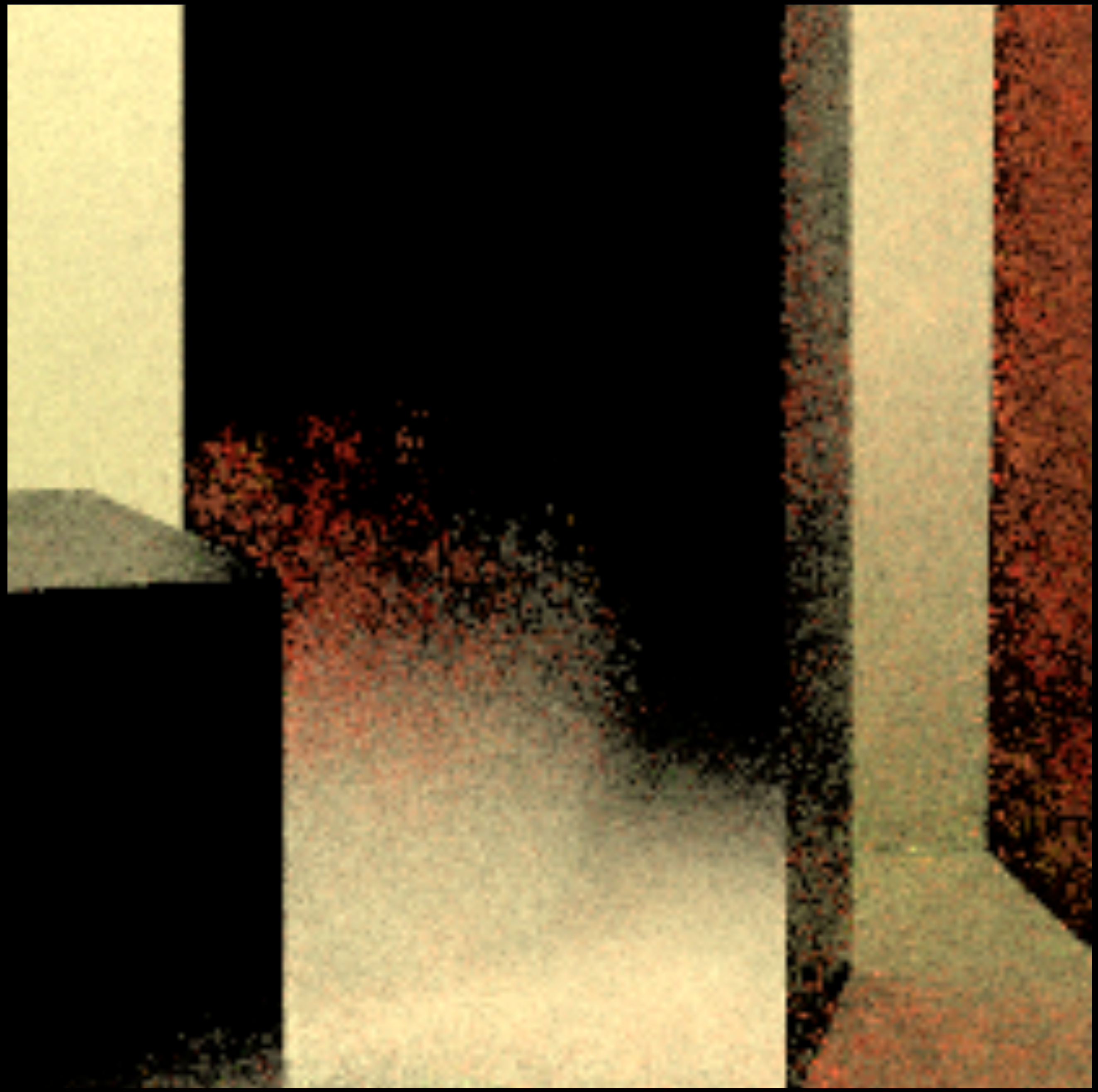


MEMLT (RMSE: 0.1374)

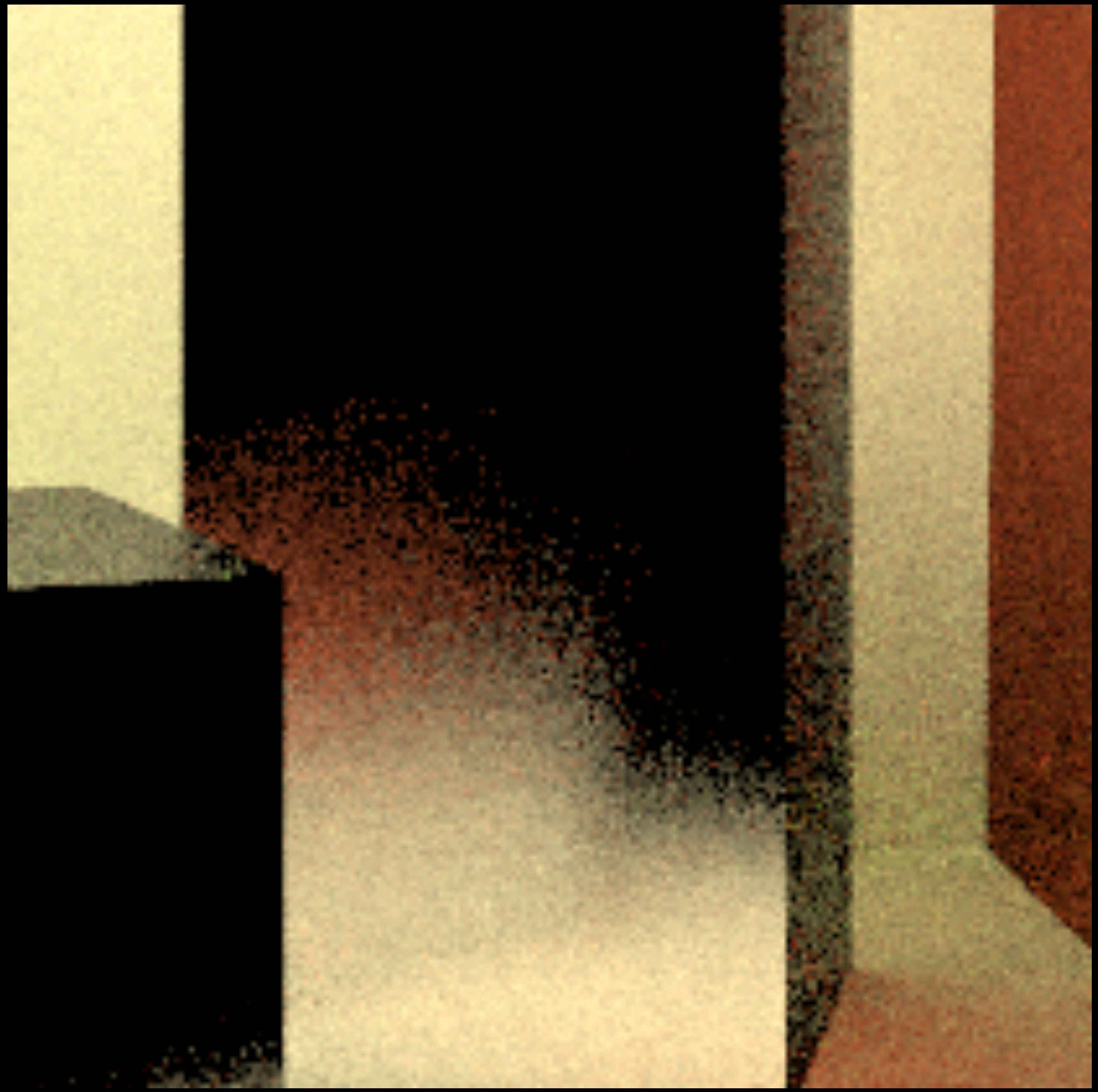


MMLT (RMSE: 0.1529)

Comparison with manifold exploration



MEMLT (RMSE: 0.1374)



MMLT (RMSE: 0.1529)

Limitations

- Common limitations as other MCMC methods
  - Lack of stratification, undesirable low frequency artifact, no reliable convergence test etc.
- Specular-diffuse-specular paths cannot be captured
  - Potential combination with UPS/VCM in future

Summary

Conclusion

- First fusion of Markov chain MC and multiple importance sampling
  - MC chain explores both technique and sample spaces
  - Automatically switch to proper sampling techniques

Multiplexed MLT is **very** practical

If your rendering system already uses Kelemen MLT and BDPT, there is basically no reason not to use multiplexed MLT!

- **Easy** to implement on top of Kelemen MLT + BDPT
- Works reasonably well across **many** scenes
- Example code is **available** on my webpage

http://www.ci.i.u-tokyo.ac.jp/~hachisuka/smallmmlt.cpp