SIGGRAPH2004

Shadow Mapping

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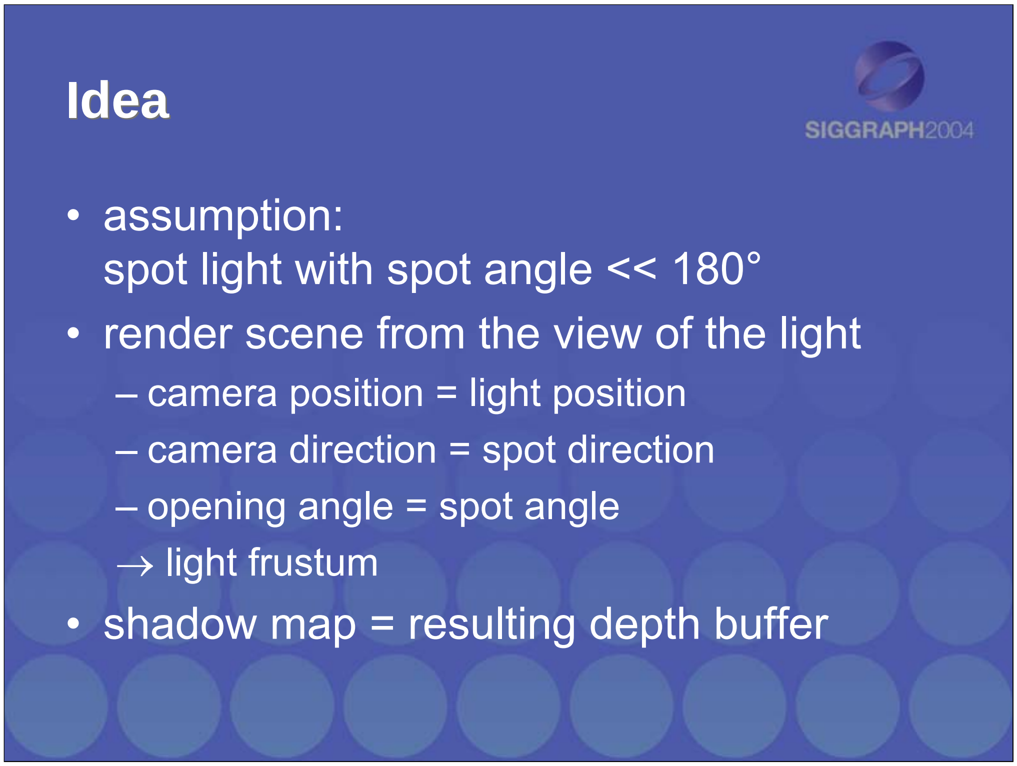
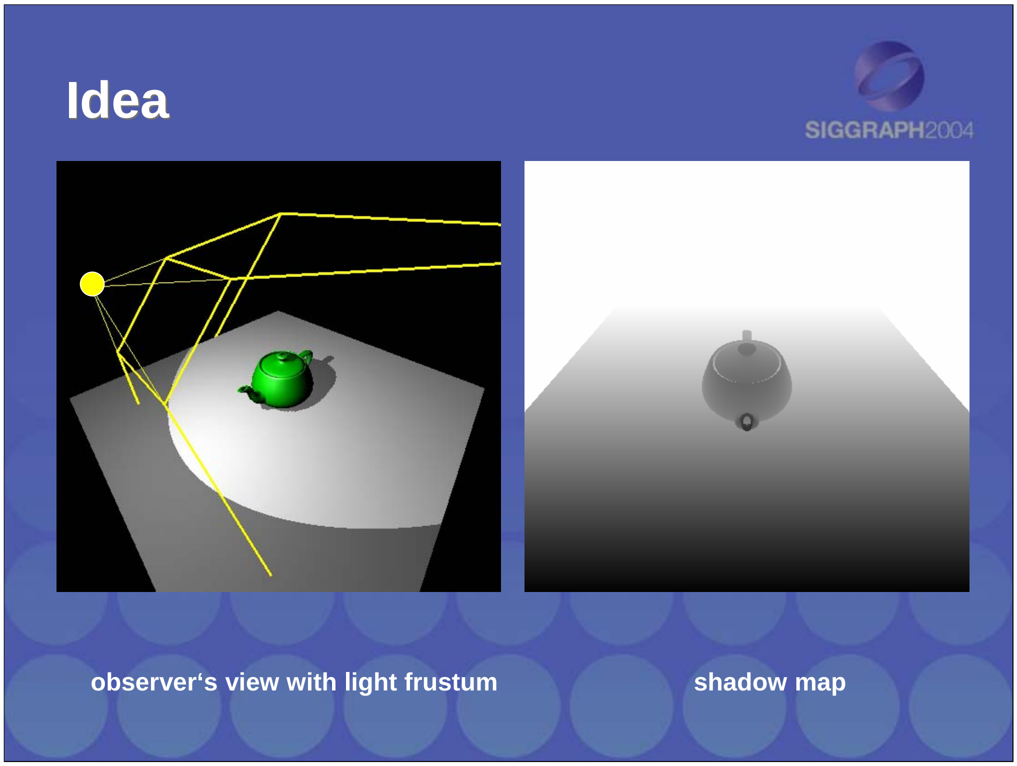
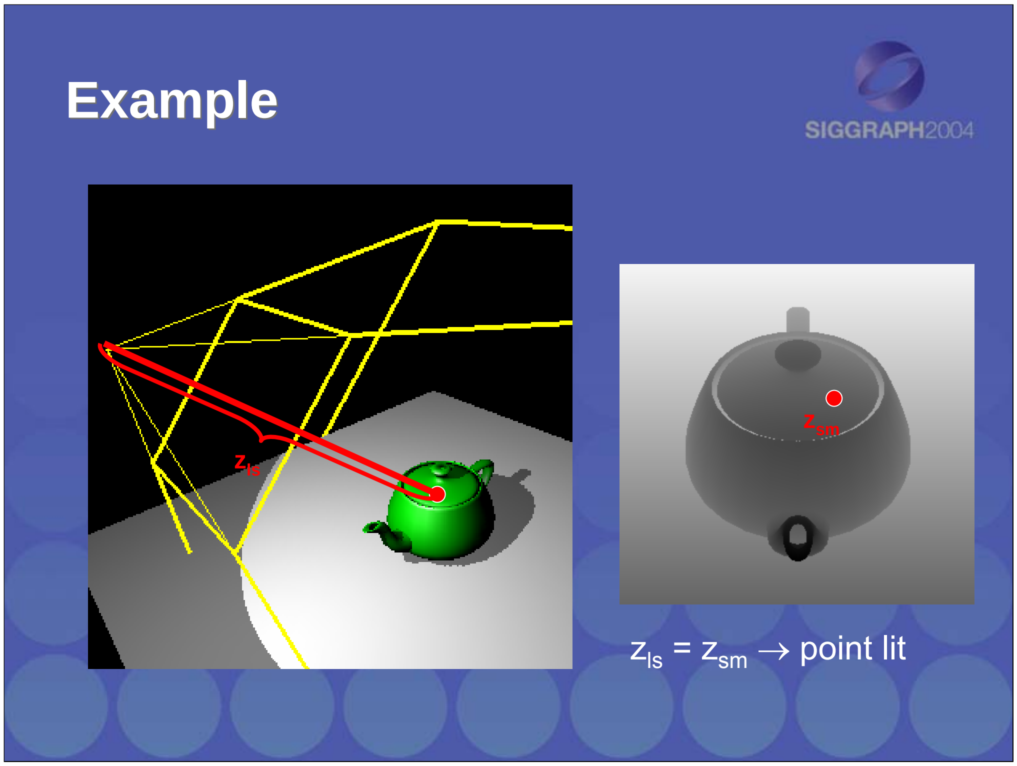


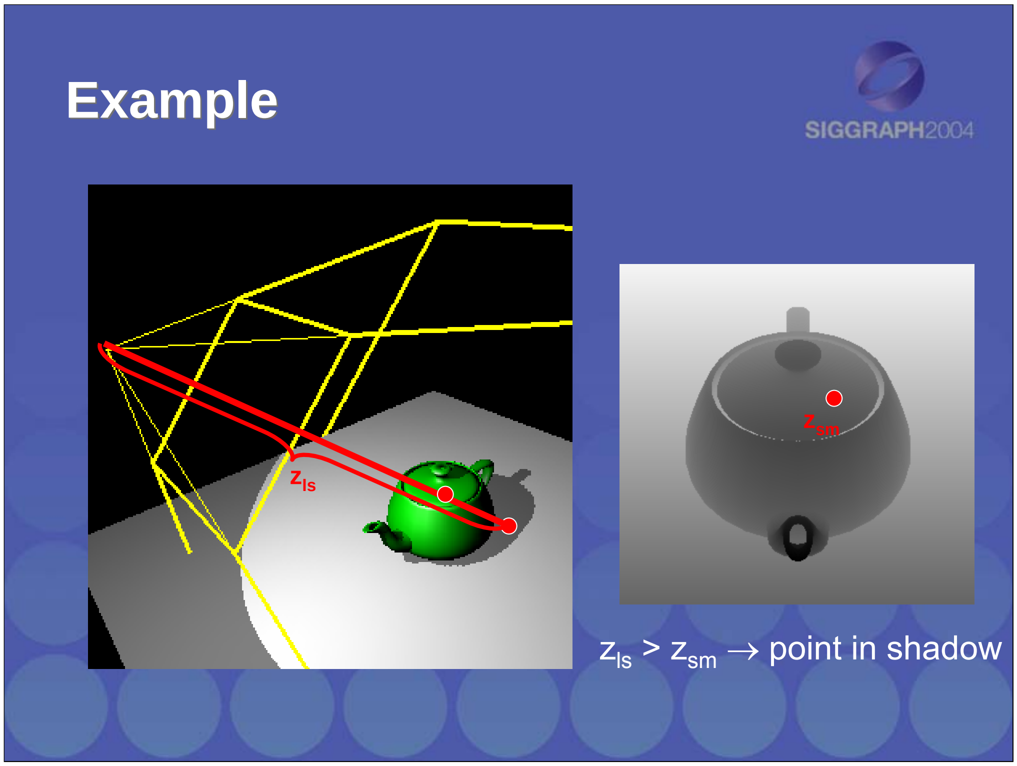
Mostly, shadow maps are generated for spot lights. All scene points illuminated by such a spot light are also visible by a perspective camera in the light source. We thus render the scene from the view of the light source and store the depth buffer as „shadow map“.



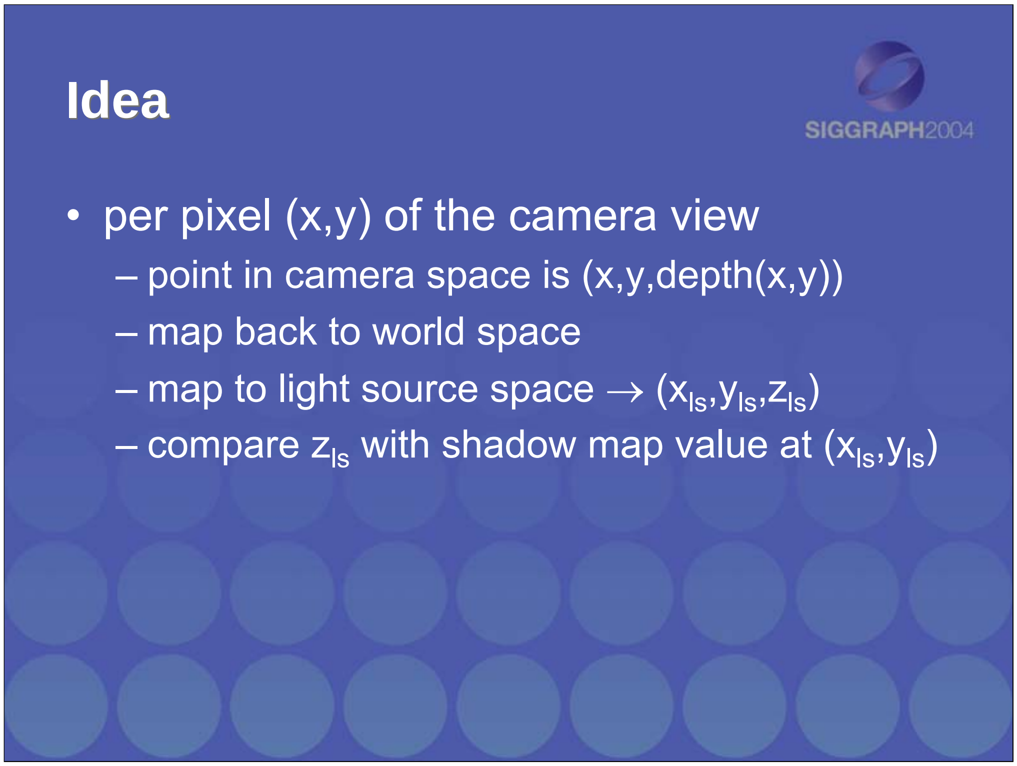
On the left one can see a simple scene, illuminated by a light source from the left. The corresponding shadow map is on the right.



In order to determine whether a point is in shadow, we compute its distance to the light source z_ls and compare it with the corresponding depth value z_sm in the shadow map. If z_ls = z_sm, the point is visible from the light and thus lit.



Another point behind the teapot has a larger distance to the light z_ls. Its projection in the shadow map is at the same position, but this time z_ls > z_sm. Thus the point is in shadow.



This is what we have to do per pixel more precisely.

Idea

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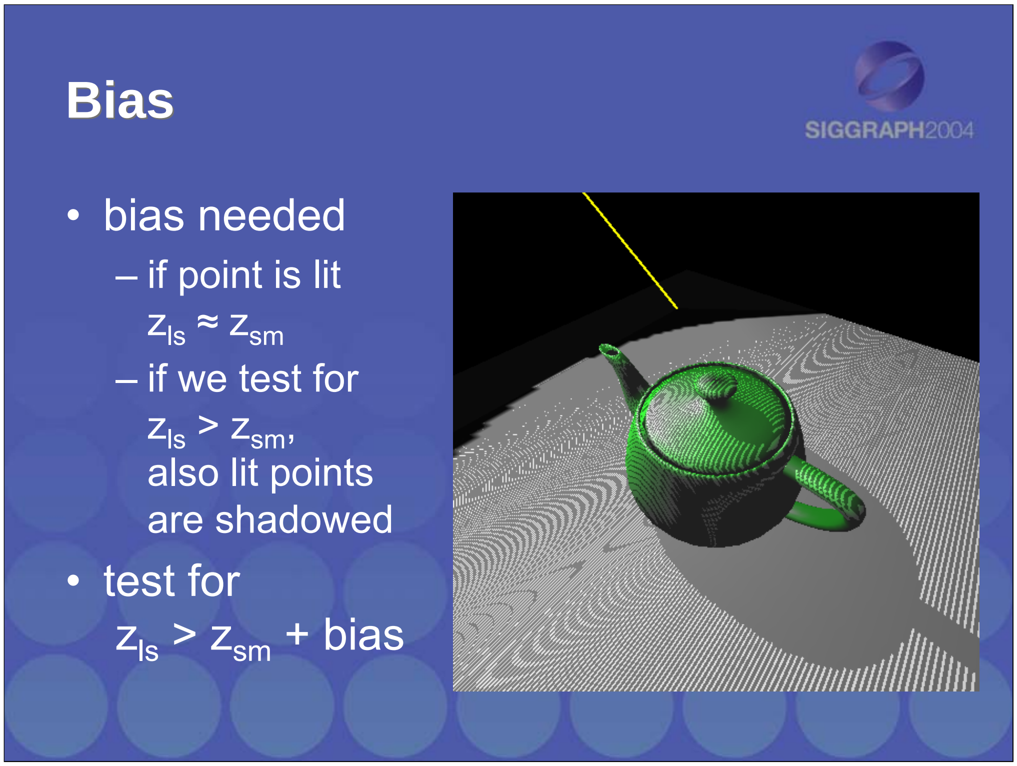
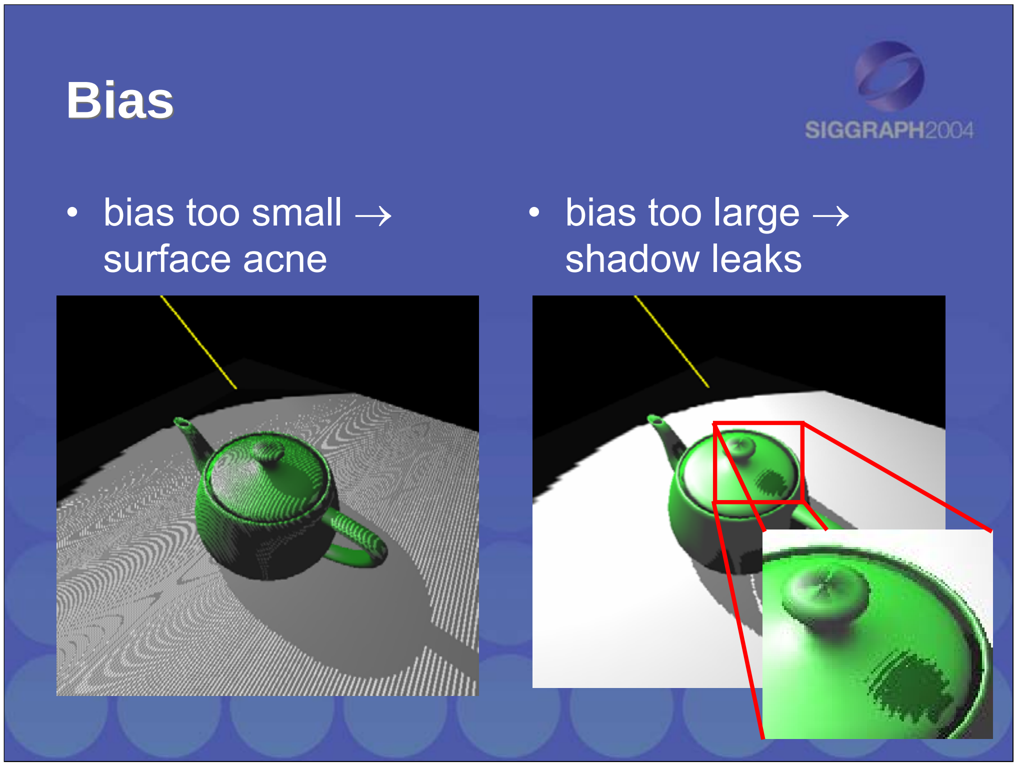
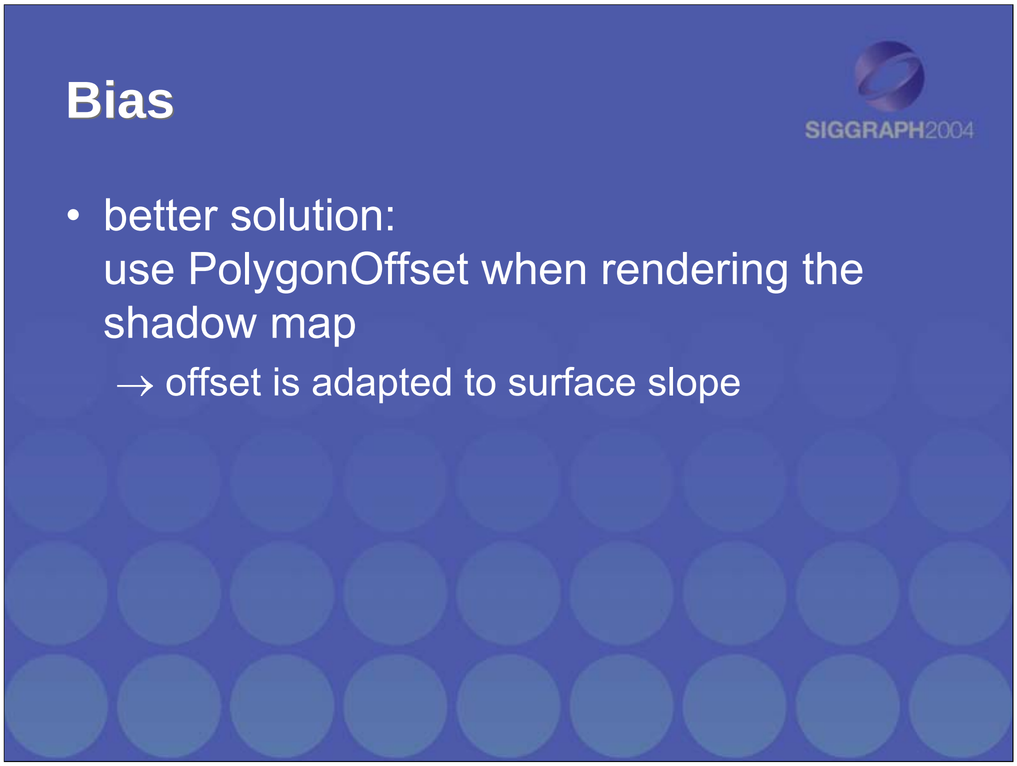
- demo „shadowmaps“



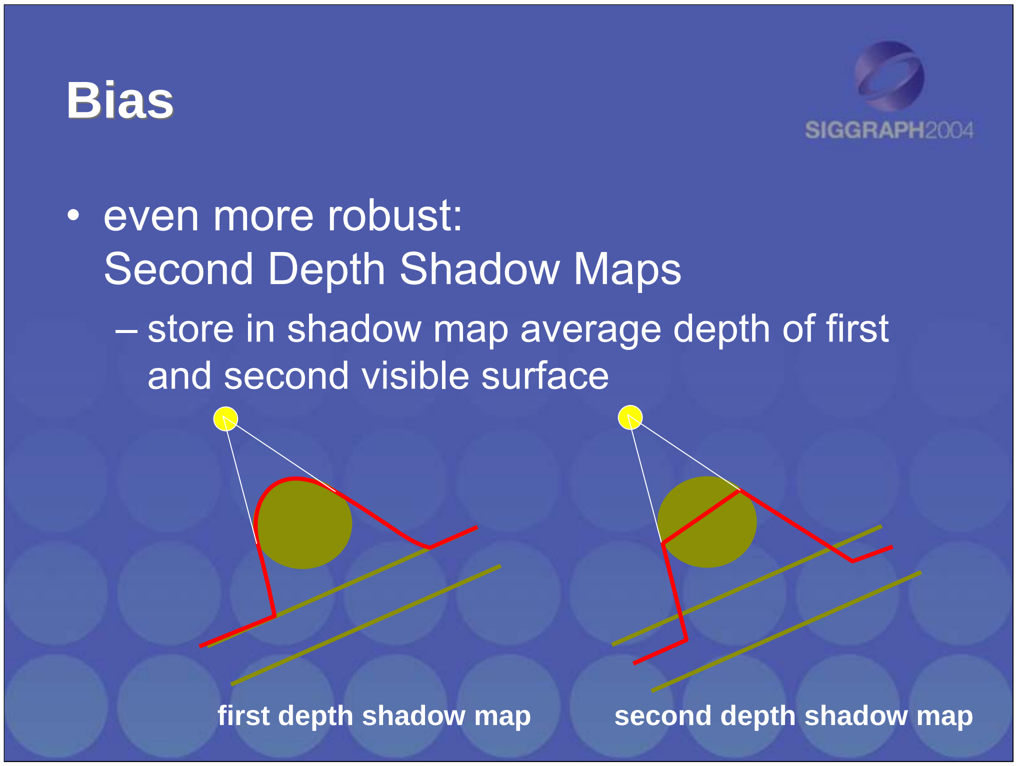
The „lit“ condition z_ls = z_sm is usually not fulfilled for lit points, because of numerical inaccuracies. So we have to define a corridor around z_sm and classify all points as lit, as long as |z_ls – z_sm| < epsilon. Because the case z_ls < z_sm cannot appear (except for numerical reasons), we can replace the test by z_ls > z_sm + bias.



The bias has to be chosen carefully. Too small bias results in surface acne, where surfaces shadow themselves. If the bias is too big, shadows get lost if the occluder and shadow receiver are close.



polygon offset as supported by normal hardware is an even better means for biasing, because it also considers surface slope.



Second depth shadow maps use the average between first and second visible surface from the view of the light source. By this, the shadow map depth values have maximum distance to the lit and the first shadowed surfaces. On the downside, the generation is more expensive and requires to generate the first and second visible layer from the view of the light source.

Aliasing

- finite shadow map resolution
  → pixelized shadows

The major problem of shadow maps is aliasing. Because of the image based nature of the shadow map, shadows appear pixelized, when shadow map and camera image resolution mismatch.

Aliasing

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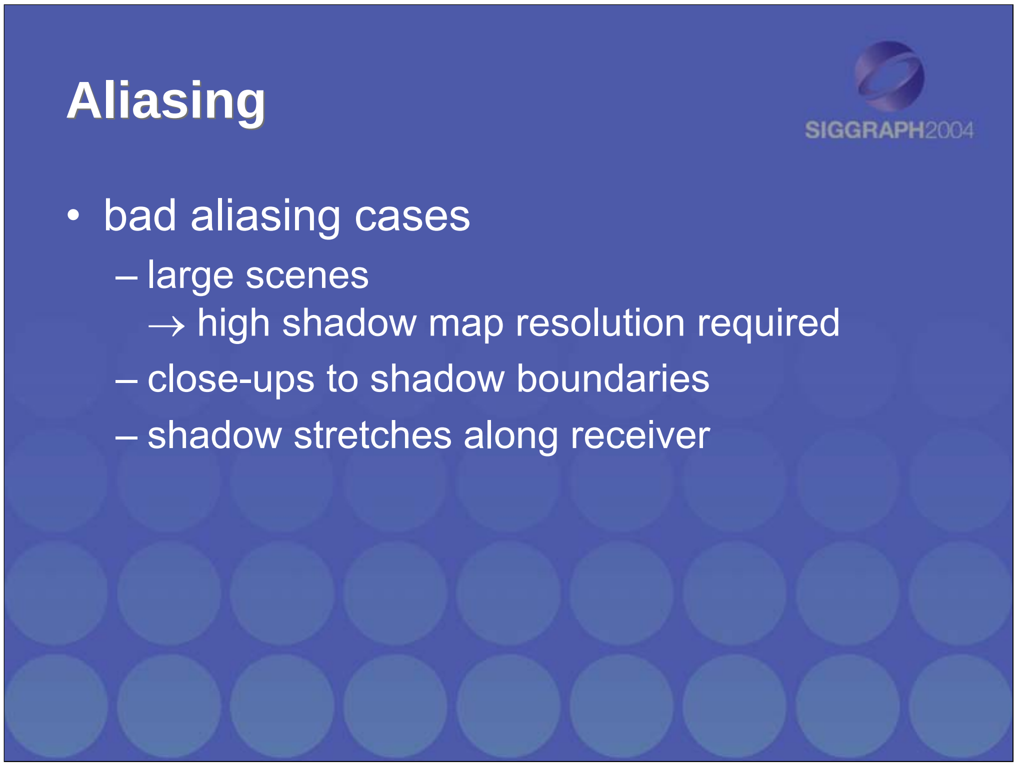
- percentage closer filtering
  - filter shadow test result 0/1 instead of depth

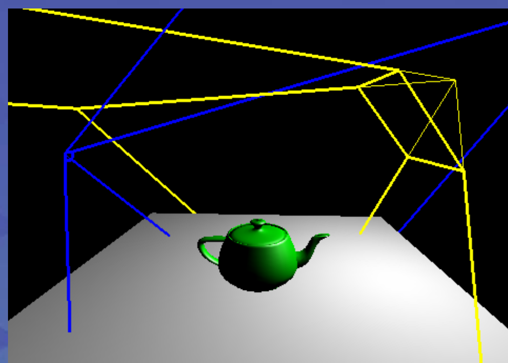
When filtering shadow maps, it is important not to filter the depth values, but the comparison results.



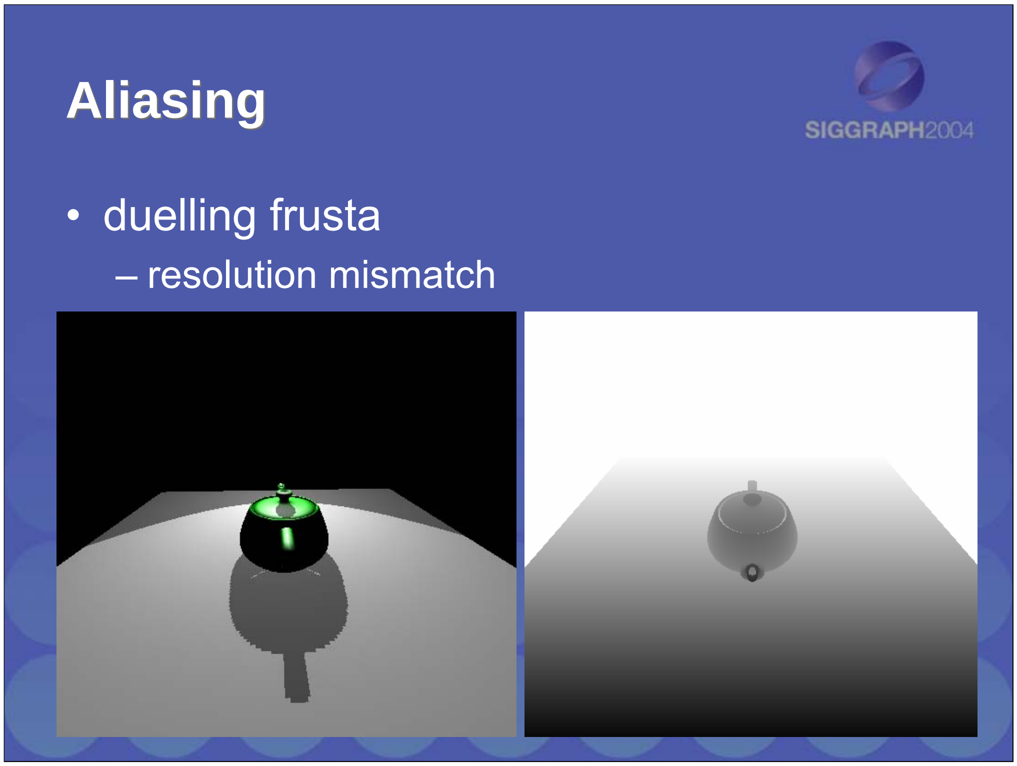
Aliasing is particular apparent for several cases. In particular for large outdoor scenes, standard shadow maps are almost useless. Furthermore, when we zoom into a shadow boundary, we can always recognize the pixelized shadow structure at some point.

Aliasing

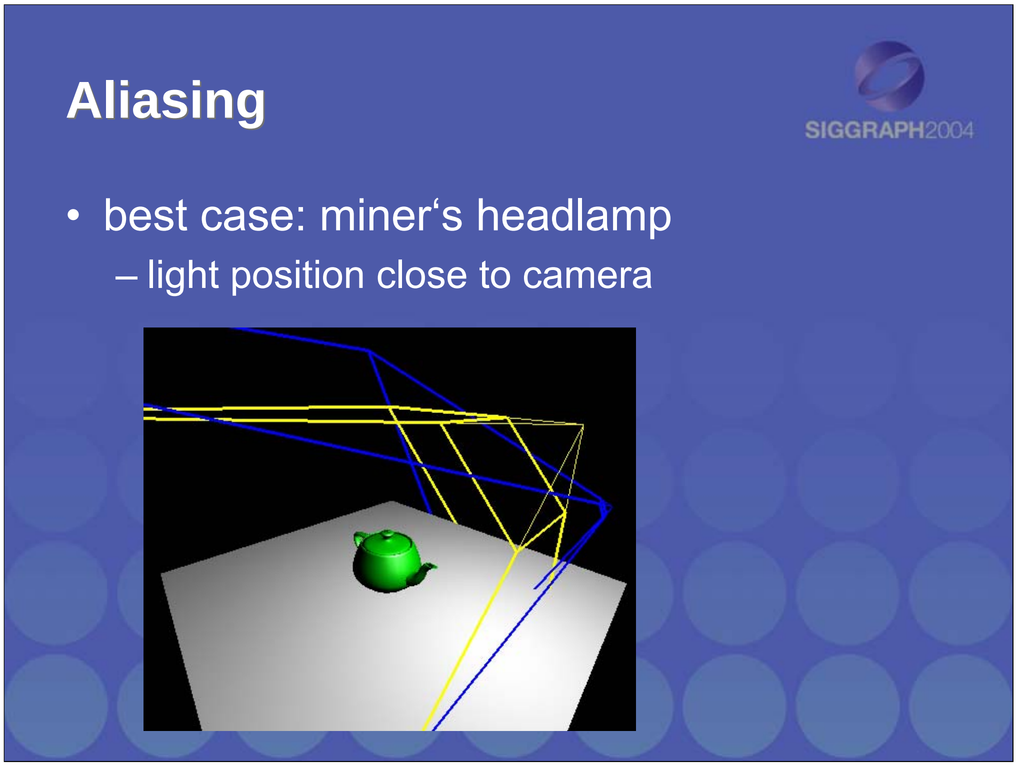
- duelling frusta
  - light shines opposite to viewing direction



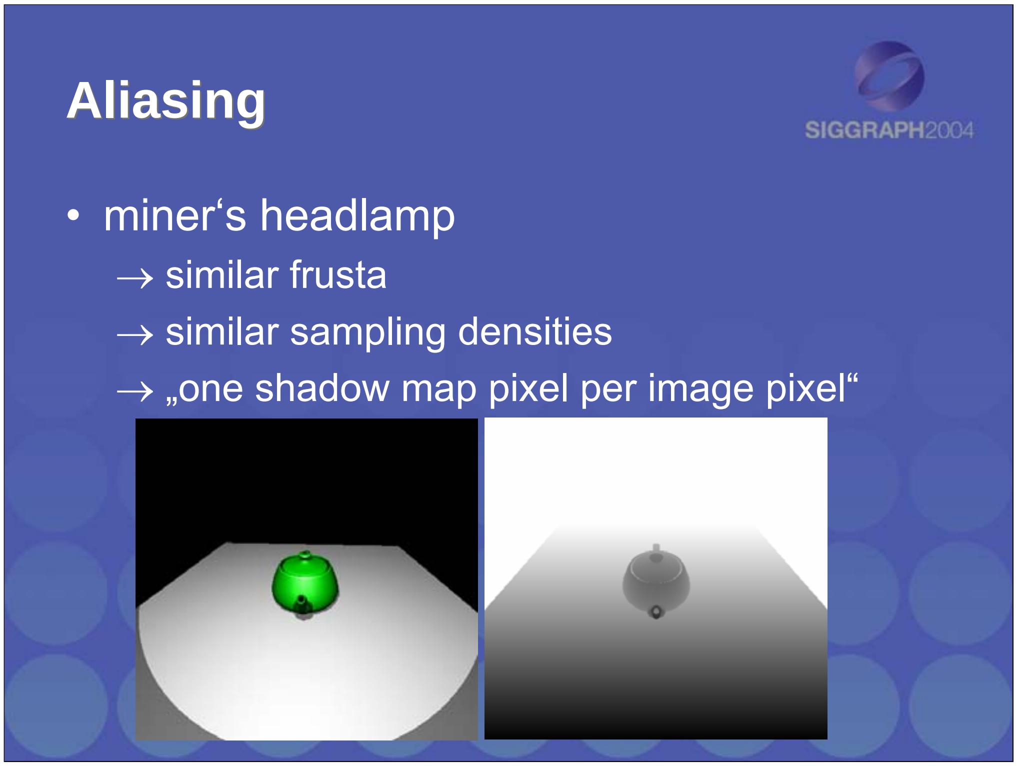
A typical bad case are duelling frusta.



For duelling frusta, the resolution mismatch is maximal. The regions that are large in the camera view, are small in the shadow map and vice versa. As a result, the shadow of the handled is clearly pixelized.



The optimal case appears if camera and light source are at similar positions.



In this case, the resolutions are similarily distributed over the scene, and we get a one-to-one match between shadow map and image pixels.

Hardware Support

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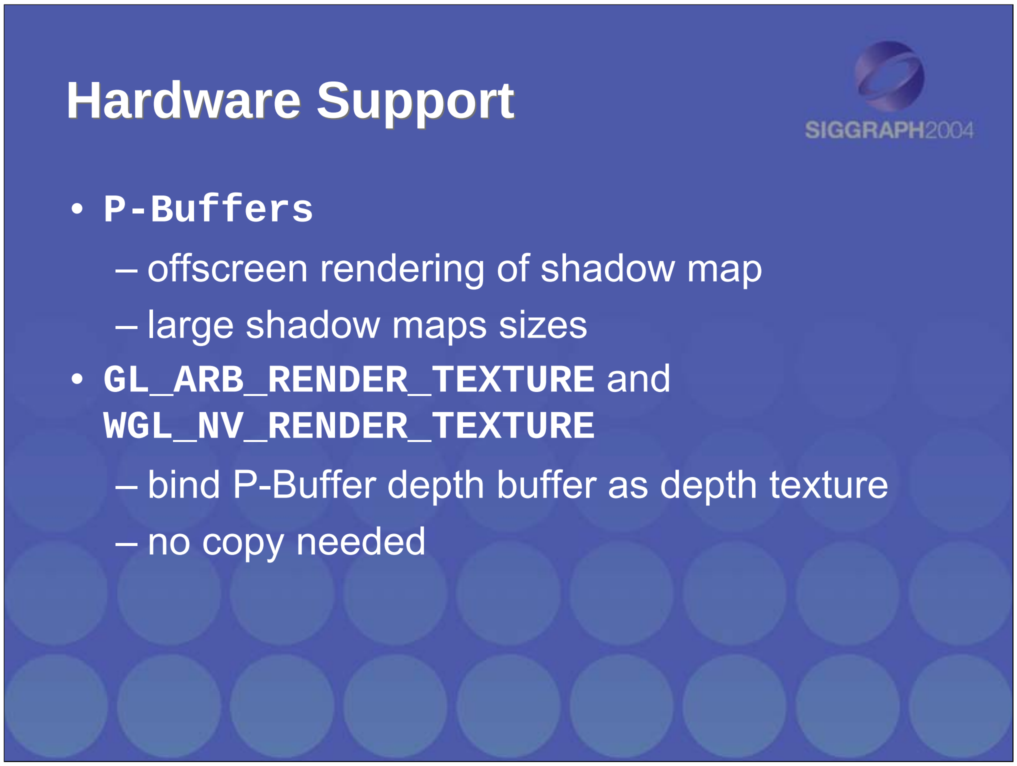
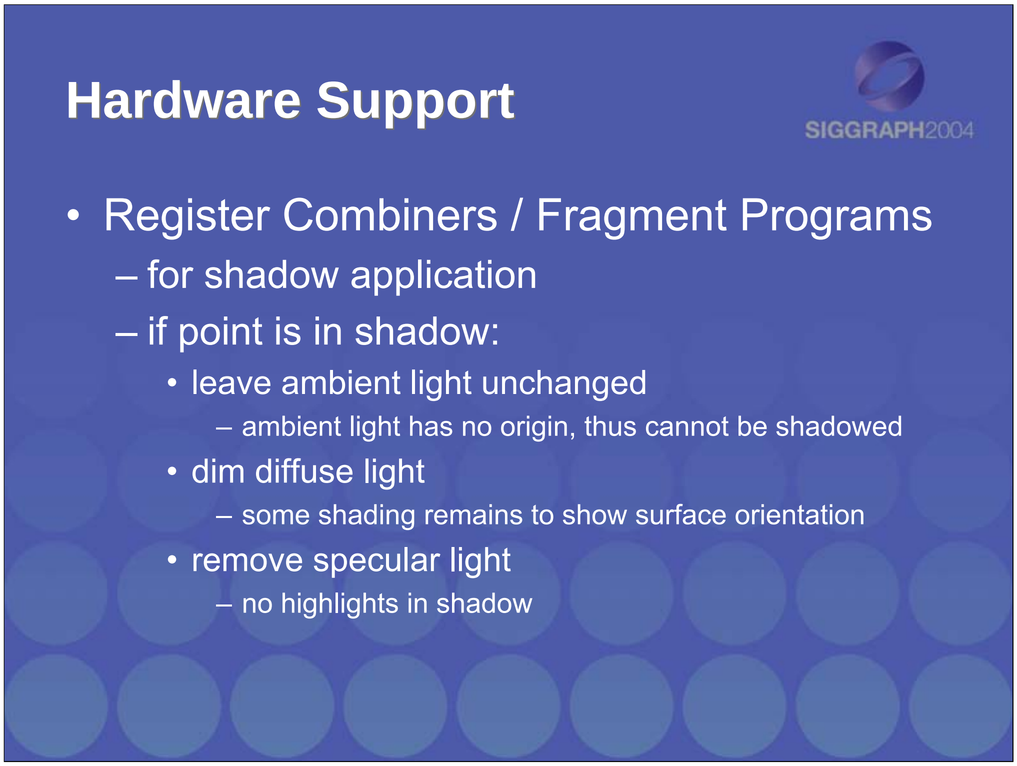
- OpenGL 1.4
  - **`GL_ARB_DEPTH_TEXTURE`**
    internal texture format to store depth values
  - **`glTexGen`**
    generation of light space coordinates as texture coordinates
  - **`GL_ARB_SHADOW`**
    special texture mode:
    `return texture(s,t) < r ? Black : White;`

The big advantage of shadow maps is that they are fully supported by hardware. In order to apply them efficiently, two extensions are necessary, which became part of OpenGL 1.4, as well as the glTexGen command.



Further improvements are possible using P-Buffers and the render to texture functionality.



Register combiners or fragment programs can be used to apply the shadows.

Pros and Cons

+ general
  - everything that can be rendered can cast and receive a shadow
  - works together with vertex programs
+ fast
  - full hardware support
  - (almost) no overhead for static scenes
  - two passes needed for dynamic scenes
+ robust
+ easy to implement

- aliasing

Extensions

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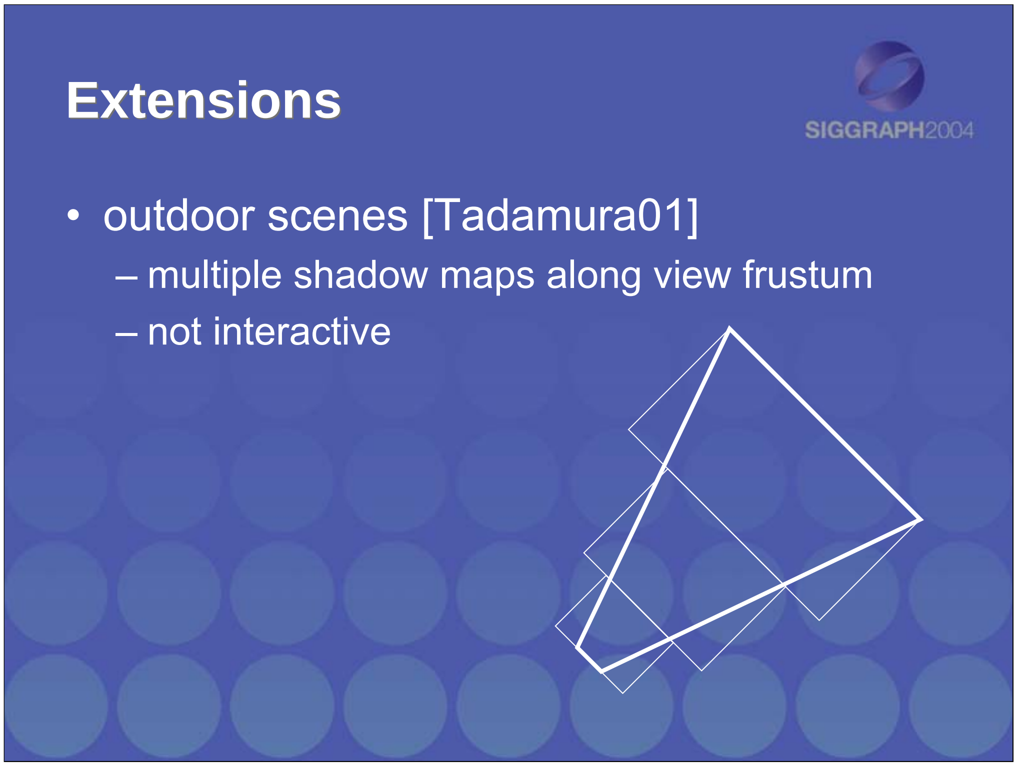
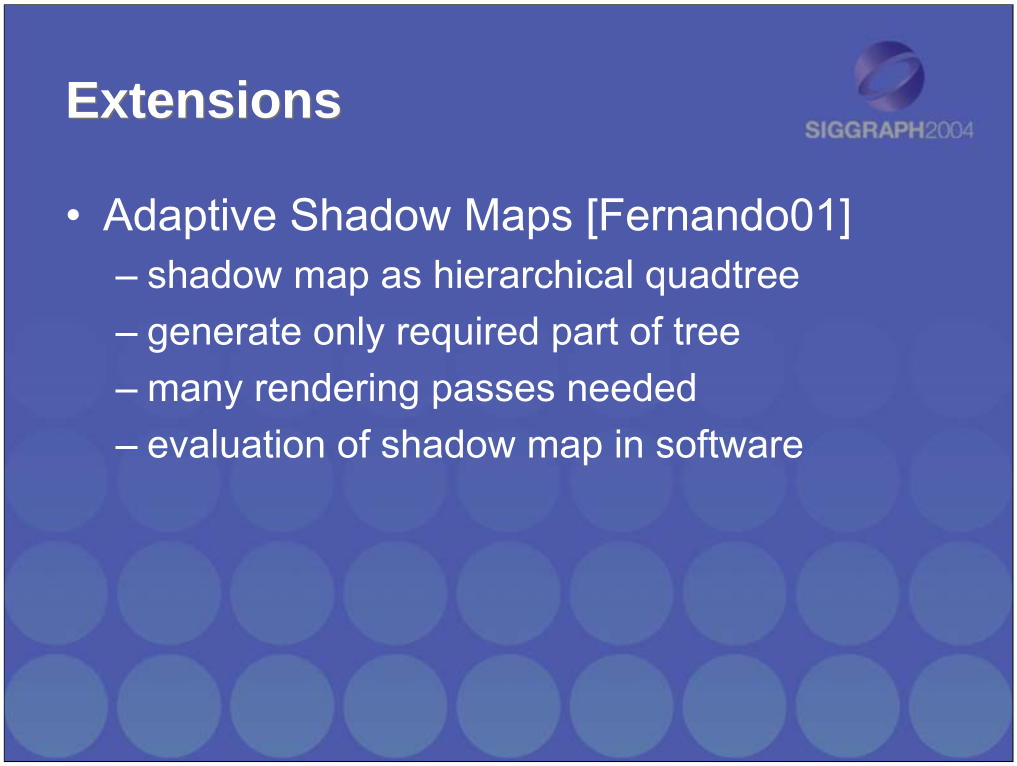
- concentrating on visible part [Brabec02]
  - – restrict shadow map to visible part of scene
  - – increased shadow map resolution
    - → less aliasing
  - – shadow map view dependent
    - → two rendering passes needed, also for static scenes

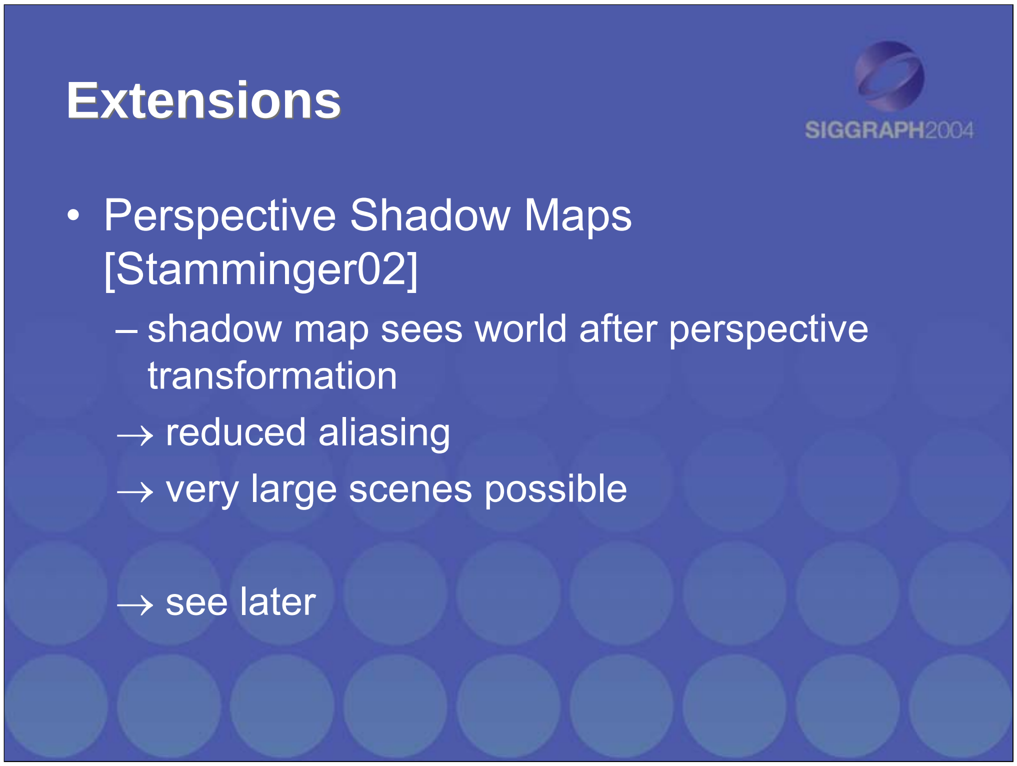
Brabec describes an efficient method to restrict the shadow map to these parts of the scene that are visible. No shadow map resolution is wasted for invisible objects. However, by this the shadow map becomes view dependent and must be regenerated per frame, which needs to be done for dynamic scenes anyhow.



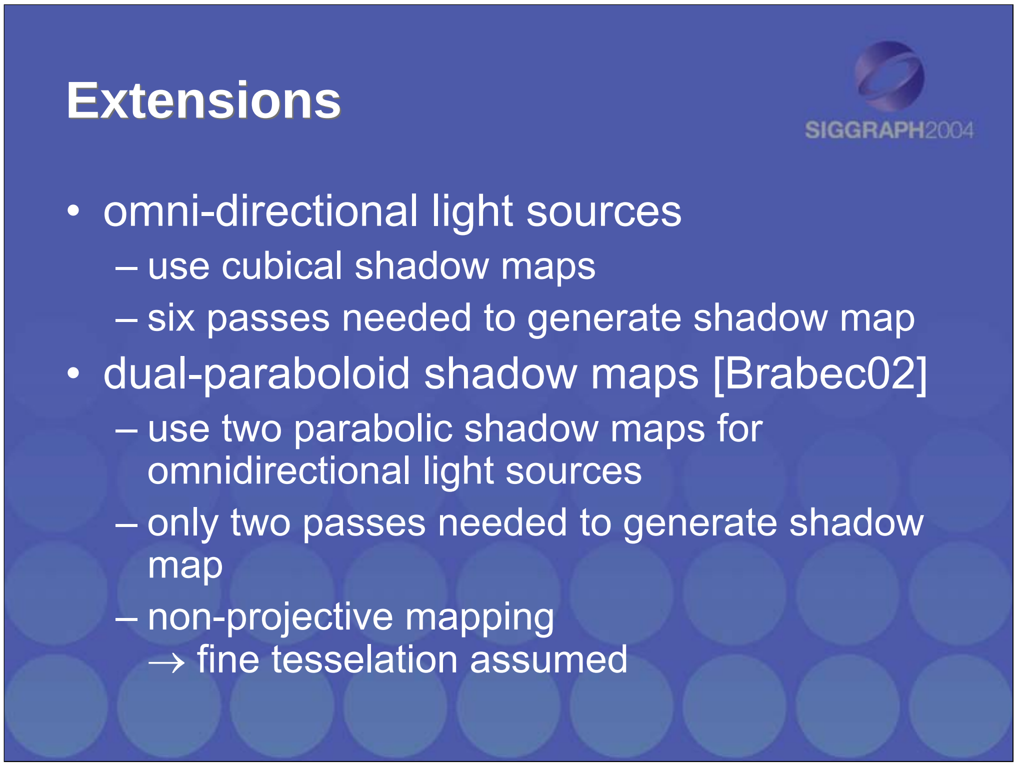
Tadamura use multiple depth buffers to cover the trapezoidal view frustum. The method is not suited for interactive rendering.



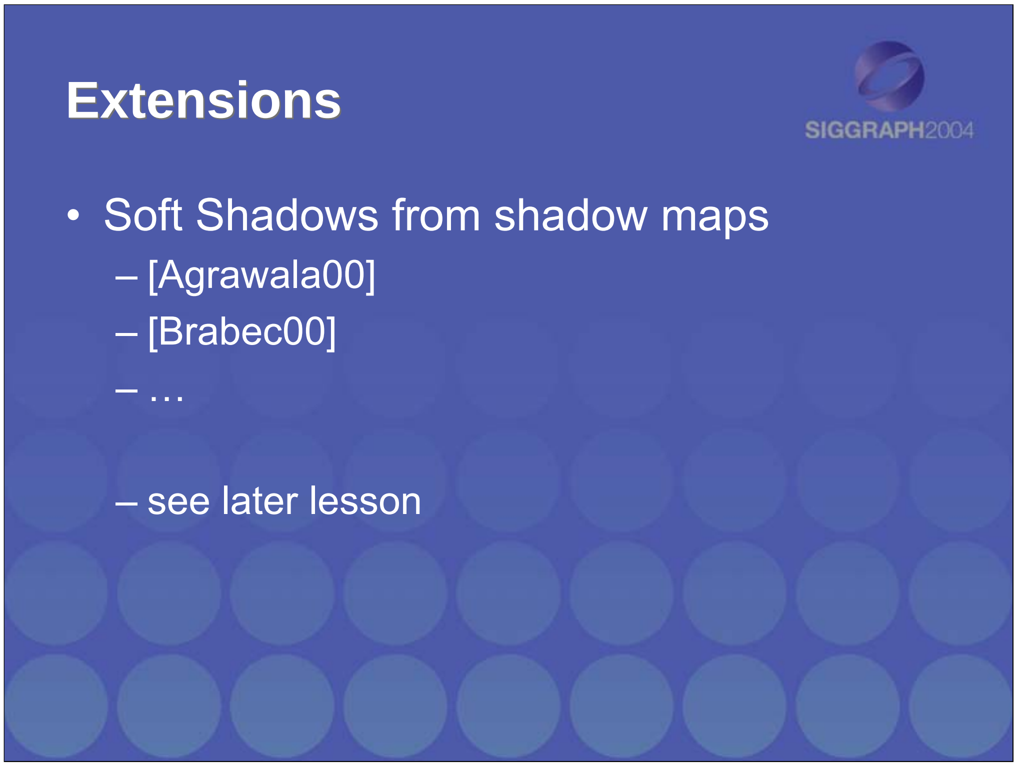
Adaptive Shadow Maps store a quadtree representation of a very high resolution shadow map. Only part of the quadtree is stored that is needed for the current view. For every frame it is determined, whether a node of the hierarchy is still sufficient or needs to be replaced by higher resolution children. The approach requires several rendering passes per frame, and the evaluation of the shadow map is not possible in hardware (yet?).



Perspective shadow maps exploit a remaining degree of freedom in the generation of shadow maps. When rendering the scene from the view of the light source, previously symmetric frusta have been used. However, by using asymmetric frusta, aliasing effects can be largely reduced in several cases. Other cases, however, remain critical and prone to aliasing. We will discuss perspective shadow maps in detail in the next talk.



As mentioned in the beginning, shadow maps are usually generated for spot lights, because their illumination solid angle can be covered by a perspective camera frustum. For omnidirectional lights, multiple shadow maps or non-projective mappings must be used.



Shadow maps can also be used to generate soft shadows. However, this requires rather involved additional computations, and the performance penalty is significant. Later, we will describe one such approach in detail [Brabec00]