

# WebGL and GPU Rendering

I have 2 questions:

1. when I write `getContext` as `webgl`, then the entire bitmap update on each render is taken care by GPU?
2. when i use `transform translate` or `opacity`, The element is shifted as new layer and doesnt trigger repaint. But the animation happens. That is taken care by GPU by re-creating the layer on each frame?

Is my observation correct?

Short answer: **you're close, but there are a couple of important corrections.**

Let's go point by point and map this to how browsers actually work.

## 1. `getContext("webgl")` — is the entire bitmap update handled by the GPU?

**Not automatically, and not in the way a normal bitmap is.**

When you use **WebGL**:

- You are **not dealing with a browser-managed bitmap** like `<canvas> 2D`.
- You are issuing **GPU commands** (draw calls, buffer updates, texture uploads).
- The GPU renders directly into a **framebuffer** (usually GPU memory).

### Key clarifications

- The browser **does not repaint a bitmap for you.**
- **Only what you explicitly change** (buffers, uniforms, textures) is updated.
- If you upload new vertex data or textures each frame, **that upload happens each frame.**
- The GPU does the rasterization and shading, but **you control what changes.**

### Example:

```
js
gl.bufferSubData(...) // uploads new data to GPU
gl.drawArrays(...)    // GPU renders using current state
```

So:

- ❌ *"Entire bitmap update is taken care of by GPU automatically"* → **Incorrect**
- ✅ *"Rendering is GPU-driven and incremental based on my commands"* → **Correct**

## 2. transform: translate() or opacity — GPU recreates the layer every frame?

**No — the layer is usually *not recreated*. It's reused and composited.**

This is the most common misconception.

### What actually happens

When you animate:

```
css

transform: translateX(...)
opacity: ...
```

The browser pipeline looks like this:

```
sql

Layout      → ❌ skipped
Paint       → ❌ skipped
Composite   → ✅ runs every frame
```

### Why no repaint?

- The element is **already painted once** into a bitmap (often called a *layer*).
- That bitmap is **uploaded once as a GPU texture**.
- On each frame:
  - The **GPU repositions or blends the same texture**
  - No pixels are repainted
  - No layout is recalculated

### Important correction

- ❌ "GPU recreates the layer each frame" → **Incorrect**
- ✅ "GPU reuses the same texture and applies a new transform or opacity" → **Correct**

Think of it like this:

The pixels stay the same — only the **matrix and alpha values change**

## Putting it all together

### WebGL

Aspect	Who does it
Drawing pixels	GPU

Aspect	Who does it
Deciding what changes	You
Automatic bitmap repaint	✗ No
Full control	✓ Yes

## CSS transform / opacity

Aspect	Who does it
Pixel generation	CPU (once)
Animation	GPU
Repaint per frame	✗ No
Layer recreation	✗ No
Texture reuse	✓ Yes

## Mental model that works well

- **WebGL** → *You are the rendering engine*
- **CSS transforms** → *Browser paints once, GPU moves the result*
- **GPU animations** → *Change math, not pixels*

If you want, I can:

- walk through **Chrome DevTools** → **Layers / Rendering tabs**
- explain **when a new layer is actually created**
- compare **Canvas 2D vs WebGL vs CSS animations**

Just tell me.

GPU reuses the same texture and applies a new transform or opacity" → Correct

but even though GPU will use same texture, after applying transform or opacity, it has to generate a new texture rut?

Great question — this is the exact subtle point where a lot of confusion happens 👍

Short answer: **No, the GPU usually does *not* generate a new texture.** It generates **new fragments (pixels) in the framebuffer.**

Let's break that apart carefully.

# Texture ≠Framebuffer (this is the key distinction)

## Texture

- A texture is **source data**
- Stored in GPU memory
- Created once (e.g. from a painted DOM layer or image)
- **Not modified** during transform / opacity animations

## Framebuffer

- The **final render target** (what you see on screen)
- Rewritten **every frame** (60fps, 120fps, etc.)
- Built by sampling textures + applying math




## What actually happens during a transform/opacity animation

Assume a layer already exists as a GPU texture.

Each frame:

1. GPU takes the **same texture**
2. Applies:
  - a **transform matrix** (translate / rotate / scale)
  - an **alpha value** (opacity)
3. Runs the fragment shader
4. Writes the result into the **framebuffer**

### Crucially:

-  No new texture is created
-  Original texture is not rewritten
-  Only the framebuffer pixels change

## Why a new texture would be expensive

Creating a new texture would require:

- Allocating GPU memory
- Uploading pixel data
- Syncing CPU ↔ GPU

That would defeat the entire purpose of compositor-only animations. Browsers explicitly avoid this.

## Simple GPU analogy

Imagine:

- **Texture** = a sticker
- **Framebuffer** = a whiteboard

Each frame:

- You move the sticker or change its transparency
- You redraw the **whiteboard**, not the sticker
- The sticker itself never changes

## What *does* get regenerated every frame?

Item	Regenerated?
Framebuffer	✓ Yes
Vertex data	✗ Usually reused
Texture	✗ No
Transform matrix	✓ Yes (tiny data)
Alpha value	✓ Yes (tiny data)

## When *would* a new texture be created?

A new texture (or repaint → texture upload) happens when:

- Content changes (**text**, **background**, **border**, etc.)
- Layout-affecting properties change
- Non-compositor properties animate (e.g. **width**, **left**, **box-shadow**)
- Filters that require offscreen rendering (**filter: blur()** often)

In those cases:

```
cpp
```

```
Paint → new bitmap → new texture upload
```

## Corrected statement you can safely use

"The GPU reuses the same texture; only the framebuffer is re-rendered each frame with updated transform or opacity values."

That's the precise, correct mental model.

If you want, I can also explain:

- why **will-change** helps *sometimes*
- how **filter** differs from **opacity**
- how WebGL's pipeline maps almost 1:1 to browser compositing

Just say the word.

still i dont undersnad how a image can change in framebuffer using old image. opacity is fine but how transform translate will work? I have a image with a glass on center and now i move the glass towards the right corner. so u are saying the image in frame buffer is same but the entire image is moved and shown as if that one glass moved(a different layer)?

This is a *very* good question — you're not missing something trivial; you're bumping into how GPUs **actually draw images** versus how we intuitively imagine them.

The confusion comes from thinking:

"The image itself must move inside the framebuffer"

That is **not** what happens.

Let's rebuild the picture from first principles.

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## The crucial idea (one sentence)

**The GPU never "moves pixels."**

**It redraws the framebuffer every frame by sampling the same texture at different screen positions.**

Nothing in the framebuffer is reused from the previous frame.

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## Step 1: Forget the previous frame exists

A framebuffer is not like a Photoshop canvas that gets edited.

Each frame:

- The framebuffer is **cleared**
- The GPU **draws everything again**

So there is no "old image in the framebuffer" being moved.

## Step 2: How an image is actually drawn (even without animation)

When the browser draws your image layer, it does this:

1. Creates a **rectangle (two triangles)**
2. Attaches the image as a **texture**
3. For each pixel covered by the rectangle:
  - Sample the texture
  - Write the color into the framebuffer

So the image is *never copied pixel-for-pixel*.  
It is **reconstructed every frame** by math.

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## Step 3: What transform: `translate()` *really* means

Let's say your image (glass in the center) is a layer texture.

### Frame N (centered)

The GPU is told:

"Draw this rectangle at position (x=500, y=300)"

The texture is sampled and written there.

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### Frame N+1 (translated top-right)

The GPU is now told:

"Draw the **same rectangle** at position (x=650, y=150)"

That's it.

- Same texture
- Same pixels
- **Different vertex positions**

The GPU:

- Does **not** move anything
- Does **not** modify the texture
- Does **not** reuse framebuffer pixels

It simply draws the rectangle **somewhere else**.

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## Step 4: Why it *looks* like only the glass moved

Because:

- Background layer is drawn first
- Glass layer is drawn afterward
- Only the glass layer's rectangle changes position

Visually, it feels like:

"Only the glass moved"

But technically:

**The entire scene was redrawn**

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## Step 5: Visual mental model (very important)

### ✗ Wrong mental model

"There is an image already on screen and the GPU slides it upward"

### ✓ Correct mental model

"Each frame is a brand-new picture, reconstructed from layers using math"

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## Step 6: Mapping this to WebGL (to make it click)

If you've used WebGL:

```
glsl

// Vertex shader
gl_Position = projection * modelMatrix * vec4(position, 1.0);
```

- `modelMatrix` changes each frame
- `position` data stays the same
- Texture stays the same
- Framebuffer is rewritten

CSS transforms do **the same thing**, just hidden from you.

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## Why this is fast

- Changing a transform = updating **a few floats**
- Sampling a texture = extremely optimized



- No memory copy
- No CPU repaint

That's why it hits 60–120 FPS easily.

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## Final answer to your exact question

“Are you saying the image in framebuffer is the same?”

**No.**

The framebuffer is completely rewritten each frame.

“Are you saying the entire image is moved?”

**No.**

The image is **redrawn** at a different position using the same texture.

“Why does it look like only the glass moved?”

Because only the **glass layer's draw position changed**.

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## One-line summary (worth memorizing)

**Transforms don't move pixels.**

**They change where the GPU draws the same pixels each frame.**

If you want, next we can:

- draw an ASCII pipeline diagram
- compare `translate` vs `left/top`
- explain why scrolling is special

Just tell me 👍

so GPU does recreate the image in frame buffer every render

Yes — **that statement is correct**, with one very important precision.

**The GPU recreates the *framebuffer* every frame, not the image (texture).**

Let me lock this in cleanly so it finally “clicks”.

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## What is recreated every render (frame)

## ✓ Framebuffer

- The framebuffer is the *final screen image*
- It is **redrawn every frame**
- This is true whether anything moved or not

So yes:

**Every render → new framebuffer contents**

## What is NOT recreated

### ✗ Image / layer texture

- The texture containing your glass image:
  - Is created once (after paint)
  - Lives in GPU memory
  - Is reused across frames
- It is **sampled**, not rebuilt

## Exact pipeline for transform: `translate()`

Each frame:

1. Clear framebuffer
2. Draw background layer
3. Draw glass layer:
  - Same texture
  - New vertex positions (translated)
4. Write result into framebuffer

No pixels are moved.

No image is re-uploaded.

Only math + sampling.

## Why this matters (performance)

Operation	Cost
Repainting image	✗ Expensive
Uploading texture	✗ Expensive
Updating transform matrix	✓ Very cheap

Operation	Cost
Redrawing framebuffer	✓ Normal GPU work

This is why:

- `transform / opacity` → smooth
- `top/left/width` → jank

## One sentence you can confidently say

“On each frame, the GPU re-renders the framebuffer by sampling existing textures with updated transforms.”

That is **100% accurate**.

If you want, I can now explain:

- why 2D canvas behaves differently
- why `position: fixed` scrolling is special
- how browsers batch compositor layers

Just let me know.

difference between texture and frame buffer/

Great question — this is the *core* concept behind everything we discussed. I'll explain it **conceptually first**, then map it to the browser.

## 1. Big picture (one sentence)

A texture is an input image stored on the GPU.

A framebuffer is the output image the GPU is currently drawing.

## 2. Texture

### What it is

- A **read-only image** (for rendering purposes)
- Stored in **GPU memory**
- Used as **source data**

## What it's used for

- Images (<img>)
- Painted DOM layers
- Canvas contents
- Video frames

## Key properties

- Sampled by shaders
- Not modified during rendering
- Can be reused across many frames

## Analogy

### Sticker

You can place the sticker anywhere, scale it, rotate it — but the sticker itself doesn't change.

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# 3. Framebuffer

## What it is

- The **render target**
- Represents the **current screen image**
- Written to every frame

## What it's used for

- Final composited result
- What ends up on your monitor

## Key properties

- Written pixel-by-pixel by the GPU
- Cleared and redrawn every frame
- Temporary — replaced continuously

## Analogy

### Whiteboard

You erase and redraw the whiteboard every frame.

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## 4. How they work together (step by step)

When drawing an image:

1. GPU sets the framebuffer as the output
2. GPU draws a rectangle
3. For each pixel in that rectangle:
  - Sample color from the texture
  - Write color into the framebuffer

So:

```
arduino
```

```
Texture (read) → GPU → Framebuffer (write)
```

## 5. Why transforms don't need repaint

For transform: `translate()`:

- Texture → unchanged
- Transform matrix → changed
- Framebuffer → rewritten

Only math changes.

## 6. Browser-specific mapping

Browser concept	GPU concept
Painted DOM layer	Texture
Compositor layer	Textured quad
Screen	Framebuffer
Transform animation	Matrix update

## 7. When textures ARE recreated

Textures are recreated when:

- Text changes
- Layout/paint properties change
- Canvas 2D redraws

- Images load or resize

Then:

```
cpp  
  
CPU paint → bitmap → upload → new texture
```

## 8. One-line memory trick

**Textures are inputs.**

**Framebuffers are outputs.**

If you want, next I can:

- explain offscreen framebuffers
- explain **filter**: `blur()` and why it's expensive
- map this to Vulkan / Metal terminology

Just say the word 🙌

so changing texture in GPU is expensive than frame buffer? when texture changing happens in GPU?

Yes — **you've got it exactly right.**

And your follow-up question ("*when does texture changing happen?*") is the right one to ask next.

## 1. Is changing a texture more expensive than drawing the framebuffer?

✓ **Yes. Much more expensive.**

**Why:**

Operation	Cost
Redrawing framebuffer	✓ Normal GPU work (fast)
Updating transform / opacity	✓ Very cheap
Sampling an existing texture	✓ Extremely optimized
Creating / updating a texture	✗ Expensive

**The expensive part is uploading data:**

- CPU → GPU transfer
- Memory allocation
- Pipeline synchronization

GPUs are built to **read textures**, not rewrite them constantly.

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## 2. What does “changing a texture” mean?

A texture “change” means:

- New pixel data
- Or different size
- Or different content

This requires:

```
nginx

CPU bitmap → upload → GPU texture
```

That upload is the slow step.

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## 3. When does texture changing happen in browsers?

Here are the **real, concrete cases** 🙌

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### ① DOM repaint (very common)

Any time the browser must repaint an element:

```
css

color
background
border
box-shadow
text
```

Pipeline:

```
cpp

Style → Layout → Paint → Upload new texture
```

Examples:

- Changing text content
- Hover effects that change background color

- Animating `box-shadow`

## ② Animating non-compositor properties

```
css

top
left
width
height
margin
padding
```

Each frame:

- Layout recalculated
- Paint happens
- Texture updated each frame ❌

This is why these animations jank.

## ③ Canvas 2D redraw

```
js

ctx.clearRect(...)
ctx.drawImage(...)
```

Every draw:

```
cpp

CPU rasterizes → upload → new texture
```

Canvas 2D is CPU-heavy.

## ④ WebGL texture updates

```
js

gl.texImage2D(...)
gl.texSubImage2D(...)
```

You explicitly upload new pixel data.

Used for:

- Video textures
- Dynamic atlases
- Streaming data



## ⑤ Image or video frame changes

- Image loads
- Video advances frame

Each new frame = new texture data (or texture update)

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## 4. When does texture NOT change?

Texture stays the same when:

- `transform`
- `opacity`
- `will-change: transform`
- Scrolling (often)

Only the **draw position** changes.

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## 5. Why browsers work so hard to avoid texture changes

Because:

- Uploads stall the GPU pipeline
- Kill battery life
- Drop frames

That's why browsers:

- Promote elements to compositor layers
  - Cache textures
  - Encourage `transform` animations
- 

## 6. Short rule you can rely on

If pixels change → texture changes → expensive

If only position/blending changes → framebuffer redraw → cheap

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## 7. Final mental model (lock this in)

- Texture = *what*
- Transform = *where*
- Framebuffer = *result*

Change **what** → expensive

Change **where** → cheap

---

If you want, next I can:

- show how DevTools reveals texture uploads
- explain **filter** vs **opacity**
- explain why **will-change** can backfire

Just tell me 👍