Data Center

Use water cooling for your data center

Cooling amounts to ~30% of the total energy consumption in data centers [5]. Evaporative cooling using water is more energy efficient than air cooling, especially for dense data centers or data centers in warmer climates [4-6].

Impact

Reduced energy consumption compared to air cooling. However, there is a higher initial cost of installment, and a non-zero risk of water damage to hardware [4]. 80% of the heat absorbed by the water can be reused, reducing energy consumption spent elsewhere [8].

Discussion Prompt

Why is putting a large data center in the middle of the desert not a good idea with regards to sustainability?

[4, [6], [8]

Data Center

Use VM migration for hotspot mitigation in your data center

Cooling amounts to ~30% of the total energy consumption in data centers [5]. Using a temperature-aware VM allocation algorithm reduces the need for cooling by allowing hotspots to idle and cool down by themselves. VMs won't be allocated in hotspots, and if a VM runs on hardware that becomes a hotspot then it is migrated to cooler hardware.

Impact

Halves the energy consumption spent on server cooling [7]. However, latency may increase significantly due to unnecessary VM migrations [1].

Discussion Prompt

Halves the energy consumption spent on server cooling [7].
However, latency may increase significantly due to unnecessary VM migrations [1].

[1], [5], [7]

Mobile

Race-To-Idle

Release resources or services as soon as possible (e.g., wakelocks, screen).

Impact

Manually releasing resources or services as soon as possible can significantly reduce energy consumption and improve the overall performance and user experience of mobile applications.

Discussion Prompt

What are some situations where you should consider racing to idle?

[3], [4], [5]

Mobile

Wifi over cellular

Delay or disable heavy data connections that are not urgent and can be delayeduntil the device is connected to a WiFi network.

Impact

Delaying or disabling heavy data connections until the device is connected to a WiFi network can reduce energy consumption, save data usage, and improve network efficiency,contributing to a more sustainable and cost-effective computing industry.

Discussion Prompt

What are examples of heavy data connections that can wait?

[1], [7], [8]

Mobile

Dark UI colors

Provide a dark UI color theme to save battery on devices with AMOLED screens.

Impact

Providing a dark UI color theme can reduce the energy consumption of mobile applications on devices with AMOLED screens, resulting in longer battery life and a more sustainable computing industry.

Discussion Prompt

Should users with AMOLED screens be forced to use dark UI colors?

[1], [4]

Mobile

Dynamic retry delay

Whenever an attempt to access a resource has failed, increase the interval of time waited before asking access to that same resource.

Impact

Using dynamic retry delay can reduce the number of unnecessary requests and improve network efficiency, resulting in reduced energy consumption.

Discussion Prompt

What are situations in which this is not a good idea, and in what situation is this possible?

[4]

Mobile

Open only when necessary

Open/start resources/services only when they are strictly necessary.

Impact

By opening and starting resources/ services only when they are strictly necessary, mobile applications can reduce energy consumption, optimize performance, and improve the user experience.

Discussion Prompt

What are situations in which this is not a good idea, and in what situation is this possible?

[2], [4]

Mobile

Avoid extraneous work

Avoid performing tasks that are not visible/valuable to the user and/or quickly become obsolete.

Impact

Avoiding tasks where the result is not visible or not relevant to the user. Avoiding these tasks can significantly reduce the energy consumption of mobile applications, leading to longer battery life and a more efficient computing system.

Discussion Prompt

What are some examples of extraneous work?

[4]

Data Center

Use VM migration for server consolidation in your data center

A VM doesn't necessarily need all of its allocated resources all the time due to variable application workloads. Elastic up- and down-scaling of VM resources combined with VM migration allows moving VMs to a minimum number of physical machines so that the remaining unused physical machines can be shut down or put into a power saving mode.

Impact

Overall power consumption of your data center may decrease by up to 30%. However, latency may increase significantly due to unnecessary VM migrations.

Discussion Prompt

Do idling servers contribute significantly to a data center's overall energy consumption?

[1]

Data Center

Carbon-friendly computing

By relocating data centers and computing infrastructure to areas that have a high proportion of renewable energy sources, computing becomes more environmentally sustainable.

Impact

This practice can significantly reduce the carbon footprint of data centers, promote the use of renewable energy sources, create jobs in the renewable energy sector, and reduce energy costs for data centers making them more cost-effective in the long run.

Discussion Prompt

Why does the location of your data center impact its carbon footprint?

[2]

Data Center

Grid-aware workload management

The amount of green energy that is available in the energy grid is highly time- and weather- dependent. By decreasing the workload in your data center when there is little green energy available, and increasing the workload when there is plenty of green energy available, you can reduce your data center's carbon footprint.

Impact

While this practice will reduce your data center's carbon footprint, it may not be feasible to delay workload until there is enough green energy available. For this strategy to be as effective as possible, you should carefully consider the location of your data center as that will affect the supply of green energy.

Discussion Prompt

How can you leverage weather patterns to optimize your data center workload and minimize your environmental impact?

[1], [7], [8]

Data Center

Networking consumes energy, too

Not only do data centers themselves consume energy through cooling and computation, but transporting data between your end-users and your data center also consumes significant energy. The further data has to be routed, the more energy it consumes. By placing your data center close to your end-users, you can reduce network-related energy consumption.

Impact

Not only is placing your data center close to your users beneficial from an energy consumption point-of-view, it also reduces latency.

Discussion Prompt

How can the proximity between data centers and end-users benefit not only energy consumption?

[3]

Artificial Intelligence

Smaller models, big impact

It is often possible to create models that are less complex, but still accurate in their predictions. This can be achieved by using optimization algorithms and reducing the number of parameters used in the model.

Impact

Creating smaller models can significantly reduce the energy consumption and carbon footprint of AI systems, while making them more accessible for use on low-power devices. This can help to democratize AI and bring its benefits to a wider audience, while reducing its impact on the environment.

Discussion Prompt

When is it worth it to sacrifice a bit of accuracy for reduced energy-consumption?

[2], [3], [8]

Artificial Intelligence

Reporting energy consumption metrics

Tracking and reporting the energy consumption of AI systems, to provide visibility into their carbon footprint and helps identify opportunities for improvement.

Impact

This practice can help to raise awareness about the environmental impact of AI and encourage organizations to adopt more sustainable practices. It can also help to identify areas where energy consumption can be reduced, leading to cost savings and a more sustainable computing industry.

Discussion Prompt

What is a simple, yet still effective way of reporting energy consumption metrics?

[1], [2], [4], [5], [7], [8]

Artificial Intelligence

Monetary cost

Convert energy usage and efficiency reports into a monetary value, to give context to otherwise abstract numbers.

Impact

Converting energy consumption metrics into monetary cost helps organizations understand the financial impact of their energy usage, and make informed decisions to reduce energy consumption. This practice encourages the adoption of more energy-efficient hardware,software, and data centers, reducing environmental impact.

Discussion Prompt

Is the fact that monetary incentives are very effective a problem or a solution?

[1], [4], [7]

Artificial Intelligence

Do we need AI?

Before implementing AI, it's important to ask whether it's truly necessary for the task at hand. Many problems can be solved with simpler methods that have a lower environmental impact.

Impact

Considering the necessity of AI before implementation can help to reduce unnecessary energy consumption and waste. It can also encourage the development of simpler, more sustainable solutions that are better suited to the task at hand.

Discussion Prompt

What are some situations where AI is used, but not necessary?

[2], [5]

Artificial Intelligence

Efficiency as an evaluation criterion

When evaluating AI models, efficiency should be considered alongside accuracy. A model that uses less energy and resources to achieve the same level of accuracy is more environmentally sustainable.

Impact

Prioritizing efficiency as an evaluation criterion can lead to the development of more sustainable AI models. It can also encourage the use of more energy-efficient hardware and data centers, promoting a more sustainable computing industry.

Discussion Prompt

Do you think this is a sensible solution?

[4]

Artificial Intelligence

The cost formula

The cost of training an AI model can be estimated using the formula Cost(R) $E \cdot D \cdot H$, which says the cost of processing a single example (E), the size of the dataset (D), and the number of hyper parameter experiments (H) all contribute to the overall cost.

Impact

Understanding the factors that contribute to the cost of training an AI model can help organizations make informed decisions about resource allocation and optimization. It can also encourage the development of more efficient and sustainable training methods.

Discussion Prompt

Does this formula help you think about ways to reduce energy consumption?

[4]

Dirty

Poor cooling design: Using air cooling as the only cooling method.

Using air to cool your data centre is convenient, but very energy inefficient. Air requires a 35°C temperature difference to cool effectively, while water only needs 15°C. Consequently, even hot water is better at cooling hardware than air.

Impact

While every location has access to air, not every location has access to cool air, especially in the warmer months. Expect to spend a significant amount of energy on air chillers to achieve the necessary 35°C temperature difference.

[10]

Dirty

Generating currency or running a Argentina-sized country?

Everybody knows that bitcoin mining is an inherently energy intensive task, but how bad is the proof of work system used by Bitcoin?

Impact

Annually it consumes as much energy as as the entire country of Argentina. Bitcoin mining costs as much energy as 48 million people consume in a year.

[3]

Dirty

Playing Fortnite might be costing you more then your holiday car trip.

Your fancy gaming PC with all its flashy RGB lights and high-end graphics card might make you feel like a tech-savvy wizard. But by playing “Fortnite” for a year you could've also driven from Amsterdam to Strassburg.

Impact

Your PS3 can use up to 220 Watts, 3 hours a day for 40 cent per kWatt, this will cost you over 90 euro's. Driving from Amsterdam to Strassburg only costs you about 70 euro's in gas.

[2], [7], [8]

Dirty

Your old XBox consumes as much energy as a fridge.

The title says it all for this one. Refrigeratoting food prolongs the shelf live of your produce, which you need in order to live. But do your really need to play more games on your XBox?

Impact

The Xbox 360 uses about 170 watts of power during average game-play, and so does your new fridge.

[1], [9]

Dirty

The realities of YouTube

The Korean music video Gangnam Style took the internet by storm. As of 2023 the video has 4,7 bilion views.

Impact

The energy consumed by users watching the video was enough so that in 2019 it has cost us more energy then the annual energy consumption of Greenland.

[6], [4]

Dirty

The massive energy consumption of ChatGPT

Some people already can't live without others think it may take over te world, few technologies have caused as much ruckus as ChatGPT. An often overlooked aspect of the chat bot however is it's massive energy consumption.

Impact

Answering queries send to ChatGPT in only the month of January in 2023 used as much energy as 175,00 thousand humans would in an entire year.

[5]

Design Patterns I

Avoid operator overloading

Operator overloading can be used in some programming languages (e.g. C++) to redefine existing operators such as '+' and '-' for user-defined classes.

Impact

Compared to writing custom-named functions, overloading may consume 45 times as much energy, primarily because it is very slow.

Discussion Prompt

Given its effect on environmental sustainability, are there still good reasons for implementing operator overloading?

[6]

Design Patterns I

Use the Observer Design Pattern in Mobile Apps

The Observer pattern is a behavioral design pattern. It is a way to ensure that all objects (the observers) depending on some object (the subject) change themselves instantly when the state of that object changes.

Impact

Implementing the Observer pattern may reduce energy consumption by ~90% for apps that continuously run in the background, checking for state changes. How the complexity of the code is affected may vary per use case.

Discussion Prompt

Can you think of possible reasons for this energy reduction?

[8]

Design Patterns I

Use the Façade Design Pattern in Mobile Apps

The Façade pattern is a structural design pattern. It lets the client communicate to a single interface (the façade) that in turn handles the communication with different subsystems.

Impact

Implementing the Façade pattern may reduce energy consumption by ~20-60% for mobile apps that continuously run in the background. It does however negatively affect the complexity of the code, depending on the use case. [6] shows it may also have a positive impact on non-mobile systems.

Discussion Prompt

Can you give examples of use cases in which the use of this design pattern would be particularly good or bad?

[6], [8]

Design Patterns I

Be careful in applying the Abstract Factory Design Pattern

The Abstract Factory pattern is a creational design pattern. It provides a uniform way in which objects are created, independently of the class implementations of those objects.

Impact

According to [8], implementing the Abstract Factory pattern may reduce energy consumption by ~60% for mobile apps that continuously run in the background. It does however negatively affect the complexity of the code. [2] and [9] however show an increased energy consumption of ~16-22%.

Discussion Prompt

How would you decide whether implementing this design pattern is a good idea?

[2], [8], [9]

Design Patterns I

Avoid the Singleton Design Pattern in Mobile Apps

The Singleton pattern is a creational design pattern. It ensures a class only has a single instance, which has a single point of access throughout the source code. The idea is that creating multiple instances of a class is resource-demanding.

Impact

Implementing the Singleton pattern may increase energy consumption by as much as 100% for apps that continuously run in the background. It does however highly depend on the use case, so it is worthwhile to test the impact on energy consumption if you believe it to positively affect the quality of your code.

Discussion Prompt

Explain how you would make the choice for or against using this pattern, during the development stage.

[8]

Design Patterns I

Optimize the Observer Design Pattern

The Observer pattern is a behavioural design pattern. It is a way to ensure that all objects (the observers) depending on some object (the subject) change themselves instantly when the state of the subject changes.

Impact

For non-mobile object-oriented applications and embedded systems, serious negative impact on energy consumption has been reported, ranging from ~30-60% increase. [7] has shown however that this overhead can be reduced to less than 10% with some compiler optimizations.

Discussion Prompt

Explain the trade-off between using and not using this pattern.

[4], [7], [9]

Design Patterns II

Avoid the Decorator Design Pattern

The Decorator pattern is a structural design pattern. It allows for dynamically adding behaviour to one object of a class, without affecting other objects of that class.

Impact

Studies unanimously agree that this pattern negatively affects energy consumption, although reported increases range from 12% to 134% to as much as 713%. [7] has not succeeded in significantly reducing this with compiler optimizations.

Discussion Prompt

Given its effect on environmental sustainability, are there still good reasons for implementing this design pattern?

[2], [6], [7], [8]

Design Patterns II

Use the Flyweight Design Pattern

The Flyweight pattern is a structural design pattern. It refers to an object that minimizes memory usage by sharing parts of its data with similar objects.

Impact

When you have a suitable use case, implementing this pattern may reduce energy consumption by as much as 50-58%.

Discussion Prompt

In what kind of application would implementing this pattern have a significant positive impact on the energy consumption of your application?

[6], [9]

Design Patterns II

Use the Interpreter Design Pattern

The interpreter pattern is a behavioural design pattern that deals with defining a grammar for a simple language, in a way that allows for efficient interpretation. It can be used whenever the problems to be solved can be represented as interpreting a (simple) domain language.

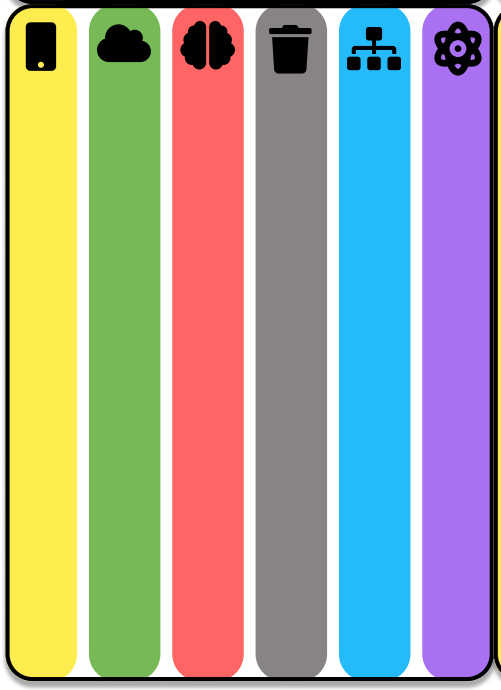
Impact

Implementing this pattern has been shown to be 33% more efficient than a non-pattern alternative.

Discussion Prompt

Can you give an example of a problem that you can change into a language interpretation problem, and efficiently solve with this pattern?

[7]



Design Patterns II

Be careful in applying the Template Method Design Pattern

The Template Method pattern is a behavioural design pattern. A 'template method' in a(n) (abstract) superclass defines the operational steps (e.g. number of steps, execution order), so that subclasses may each have their own implementation, while following a fixed format for the operation.

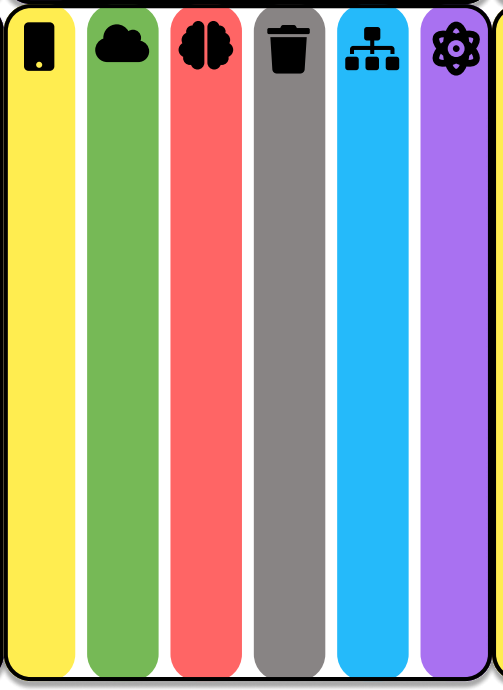
Impact

Whether the implementation of this pattern increases or decreases energy consumption depends on the use case. However, [1] and [3] have shown that an alternative to this pattern, the (Reversed) Form Template Method adapted from [4], may reduce energy consumption by 17-24%.

Discussion Prompt

Can you give examples of use cases in which the use of this design pattern would be particularly good or bad?

[1-4], [6-8]



Design Patterns II

Use an alternative for the State/Strategy Design Pattern

The State pattern is a behavioural design pattern that allows an object to change its behaviour when its internal state changes. It can be interpretated as a (also behavioural) Strategy pattern, which in general allows for selecting an algorithm at runtime.

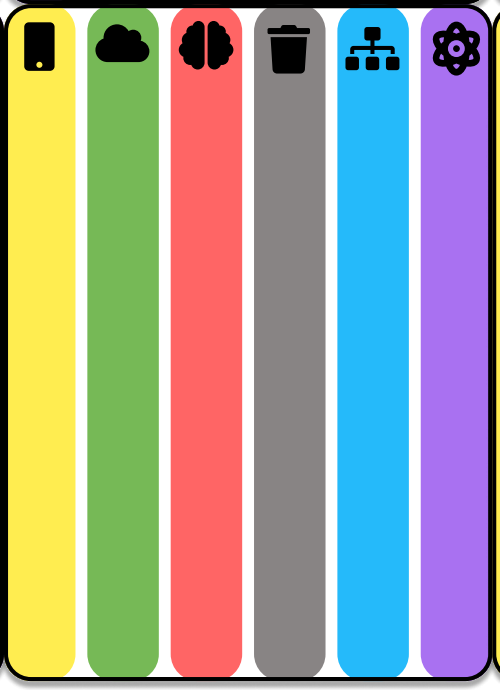
Impact

Implementing this pattern generally has an insignificant impact on energy consumption, as shown by [7] and [9]. However, [1] and [3] have shown that an alternative to this pattern, which replaces conditionals by polymorphism according to [4], may reduce energy consumption by over 50% compared to using the pattern.

Discussion Prompt

When a colleague developer suggests using this design pattern, what would you recommend?

[1], [3], [4], [7], [9]



Design Patterns II

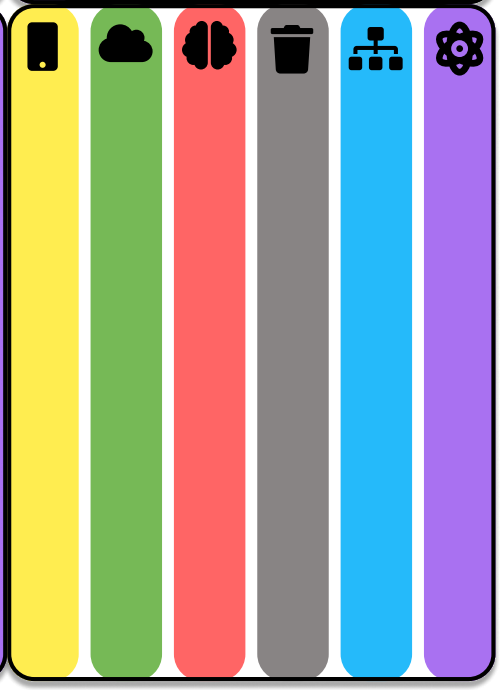
Test how your use of design patterns affects energy consumption

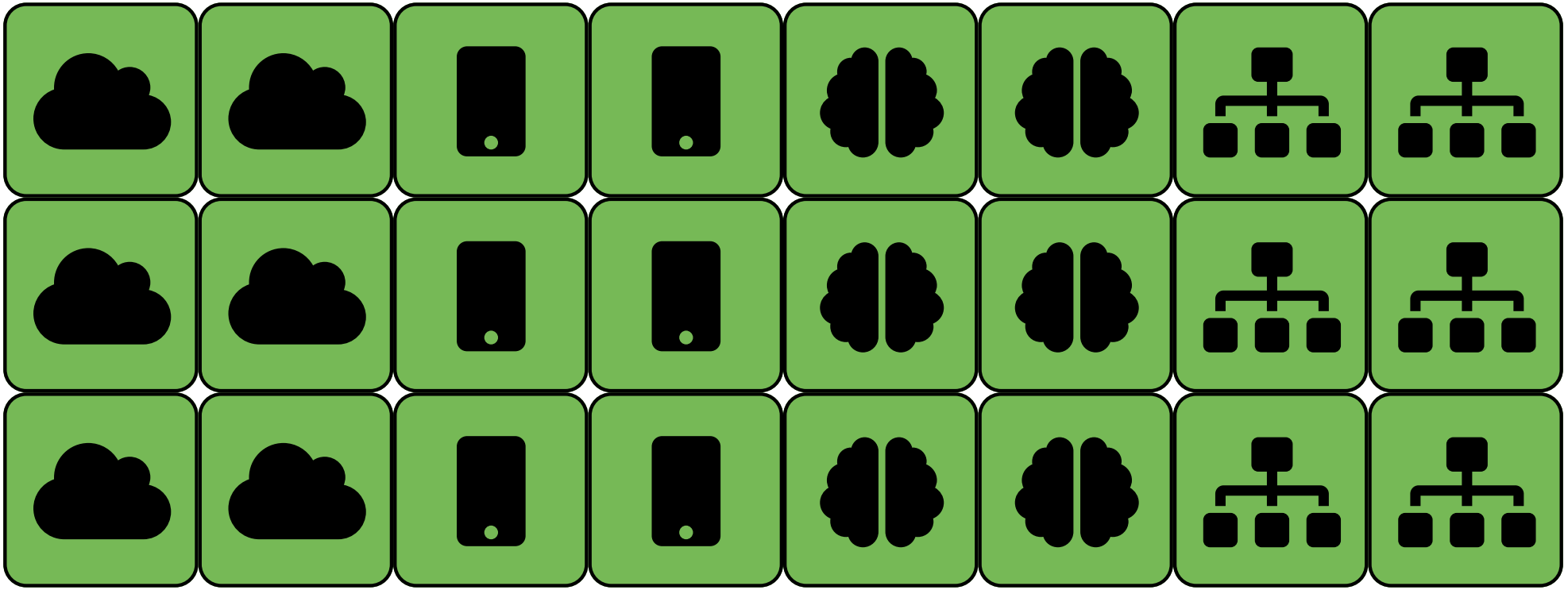
While there may be many reasons for implementing a certain design pattern, usually related to maintainability, studies are often divided on the impact of implementing a design pattern on the energy consumption of an application. It may depend on many factors, including the programming language, the specifics of the implementation, whether there are more sustainable alternatives, etc.

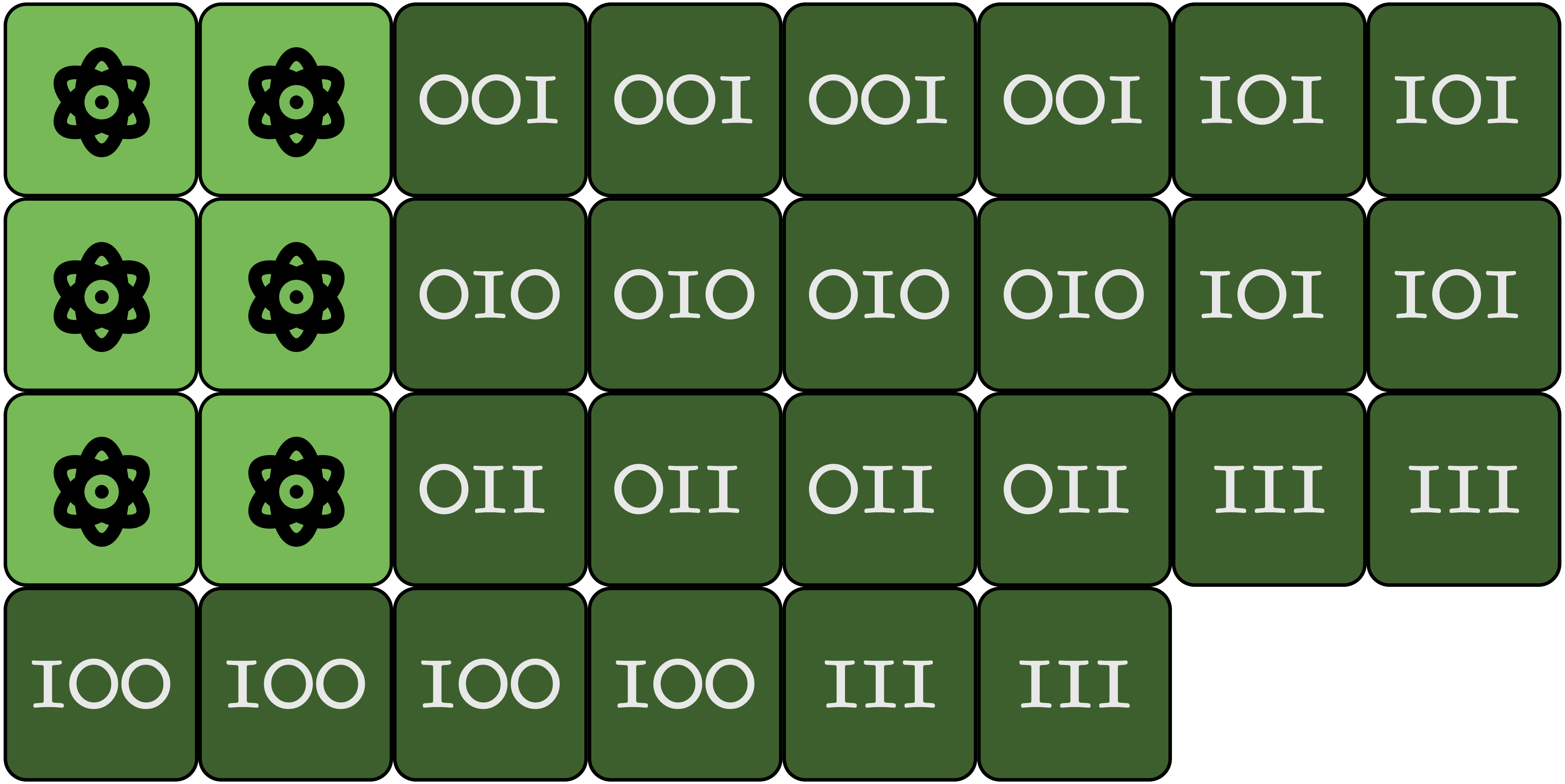
Therefore, we can only recommend that you always take environmental sustainability into account when considering a design pattern, and if possible directly testing its impact on energy consumption.

Discussion Prompt

Give an example where you would want to make use of a design pattern, and explain what effect it might have on the environmental sustainability of your application.



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