Electric Vehicles

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- Optimal Control (Optimization + Control) (Optimization of Dynamical Systems)
- Discrete time Optimal Control –Dynamic Programming
- Stochastic Optimal Control
- Discrete time stochastic optimal Control –Markov Decision Process (MDP)
- Solve an MDP in real time –reinforcement learning

- Classical Control system is generally a trial-and-error process in which various methods of analysis are used to determine the design parameters of an acceptable system.

- Economics is totally ignored in classical control. For example, the design of a spacecraft altitude control system that minimizes fuel expenditure is not amenable to solution by classical methods.

- A new and direct approach to the synthesis of these Complex systems, called optimal control theory, has been made feasible by the development of the digital computer.

- Objective - to determine the control signals that will cause a process to satisfy the physical constraints and at the same time minimize (or maximize) some performance criterion.

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Formulation of Optimal Control

→ $\dot{x}(t) = f(x(t), u(t), t)$; $t = [t_0, t_f]$

$x(t) \rightarrow n \times 1$ vector

$u(t) \rightarrow p \times 1$ "

→ $x(k+1) = f(x, u, k)$; $k \in [k_0, k_1]$

→ $u(t) \in U$ for all $t \in [t_0, t_f]$

→ $x(t) \in X$ for all $t \in [t_0, t_f]$

Minimum Time problem:

To transfer a system from an arbitrary initial state $X(t_0) = X_0$ to a specified target set S in minimum time.

$$J = t_f - t_0 = \int_{t_0}^{t_f} dt$$

Terminal Control Problem

To minimize the deviation of the final state of a system from its desired value $r(t_f)$.

$$J = \sum_{i=1}^{n} \left[x_i(t_f) - r_i(t_f) \right]^2$$

$$= \left[X(t_f) - r(t_f) \right]^T \left[x(t_f) - r(t_f) \right]$$

$$= \| X(t_f) - r(t_f) \|^2$$

$\| x(t_f) - r(t_f) \|$ is norm of a vector

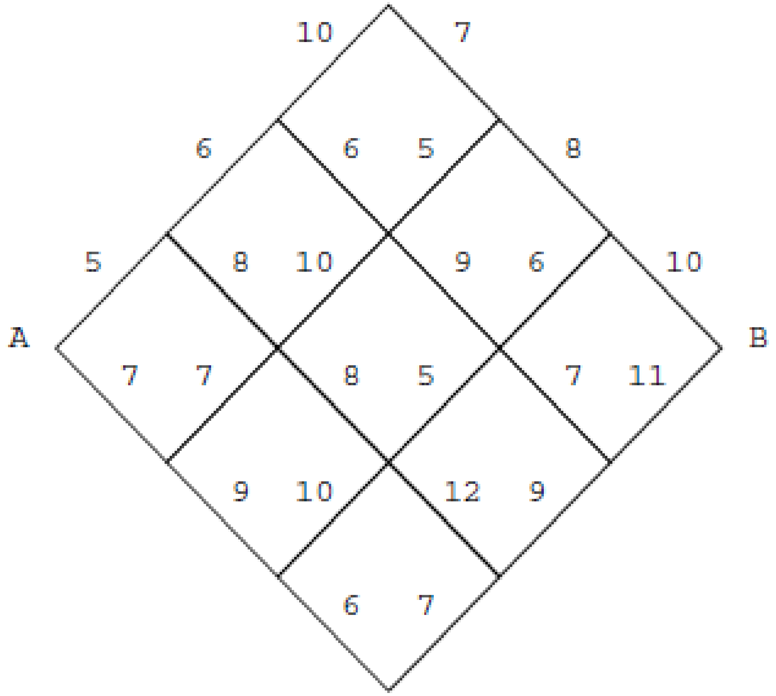
Minimum Control Effort Problems

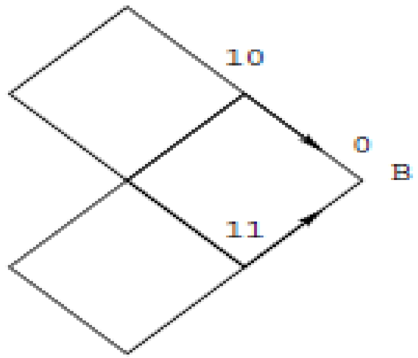
$$J = \int_{t_0}^{t_f} |u(t)|\, dt \quad , \quad \cancel{J = \int_{t_0}^{t_f} u^2(t)\, dt}$$

Minimum Energy Problems

$$J = \int_{t_0}^{t_f} u^2(t)\, dt$$

Dynamic Programming

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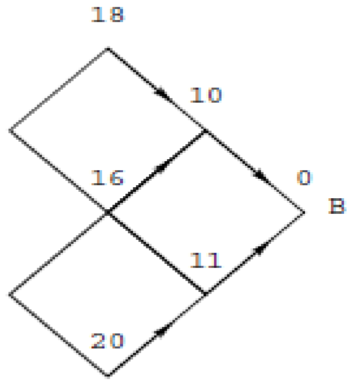
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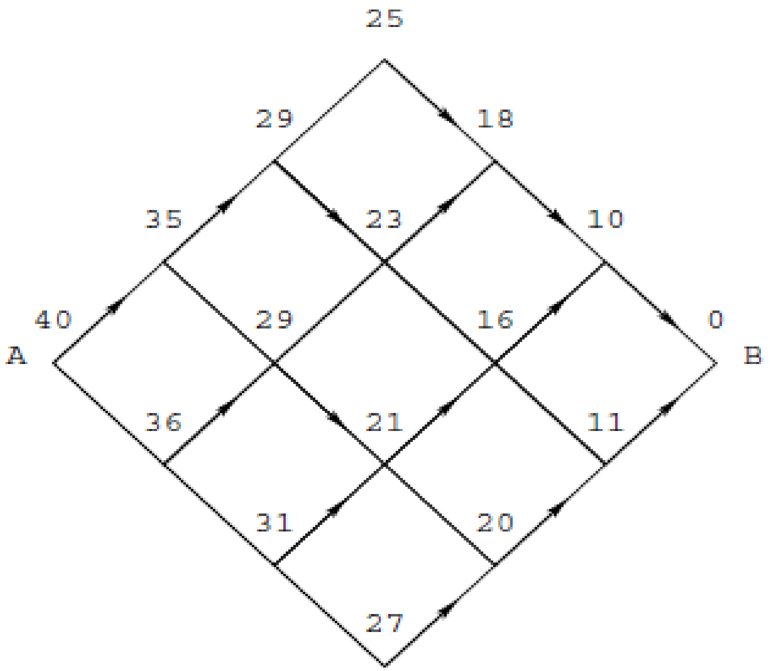
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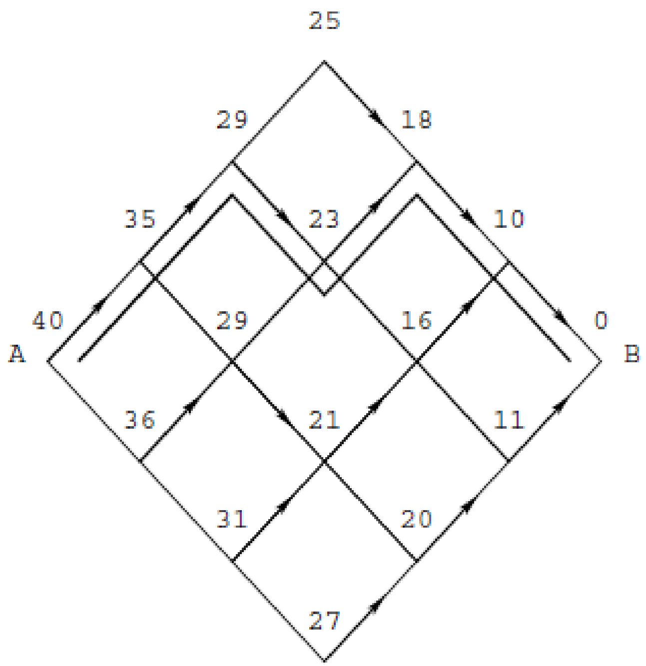
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Comparing dynamic programming with the approach of deriving all possible paths from A and B, we see that the dynamic programming leads to the calculation of 15 numbers while there are 20 possible paths. In general, for a graph with $N \times N$ vertices, we have $N^2 - 1$ cost-to-go functions to calculated compared to $(2(N-1))!/((N-1)!)^2$ paths. For example, for $N = 8$, we get 63 compared to 3432.

Electrical Motor

We already saw that electric motors are vastly superior to gasoline and diesel engines.

They are much lighter and cheaper.

They need less maintenance.

And most importantly, electric motors are three times as efficient.

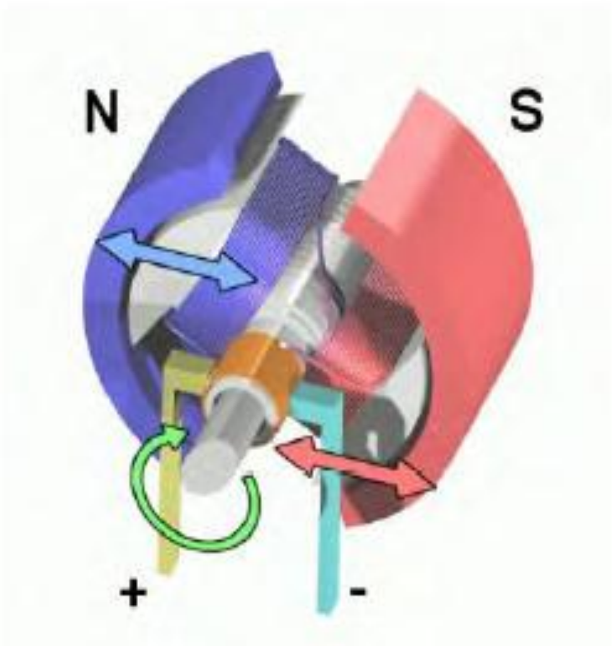
But which electric motor is best for EV propulsion?

You can look from many different perspectives.

- Mechanical engineers look at properties like size, weight and maximum torque.
- Practical builders look at things like availability, simplicity and robustness.
- Economists and business people would be interested in the purchase price and efficiency.
- Finally, people interested in the environment are interested in the use of rare earth metals and efficiency as it pertains to CO_2 emissions.

DC Motors

- This motor has a fixed part, called the stator – because it is static – that contained magnets.
- It also had a rotating part, called the rotor – because it rotates – that contains electric coils.
- Stator – fixed, and rotor – rotate.
- When you connect the coil in the rotor to the direct current produced by a battery, the current from the battery would produce a magnetic field in the rotor.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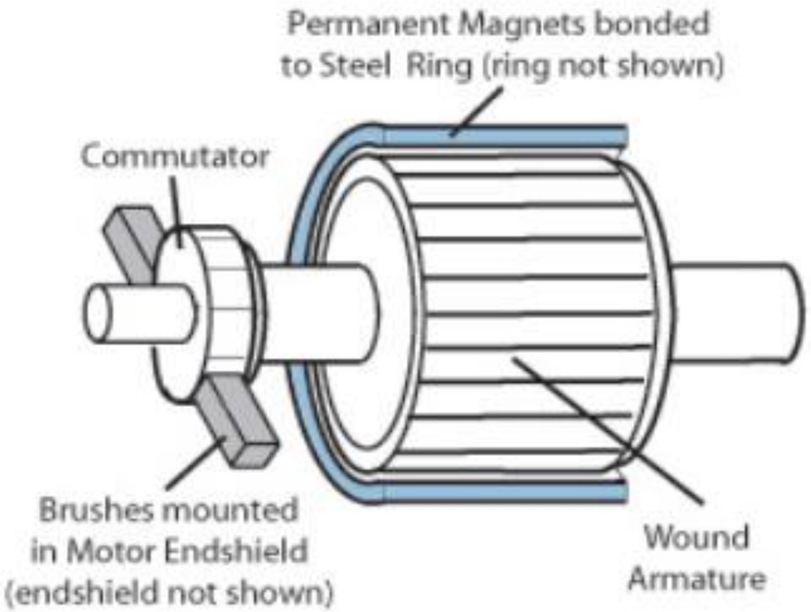
Permanent Magnets bonded
to Steel Ring (ring not shown)
Commutator
Brushes mounted
in Motor Endshield
(endshield not shown)
Wound
Armature

Materials

- **Soft magnetic materials:** Easily magnetized but lose their magnetism when the external field is removed. They are used for temporary magnets, like the cores of electromagnets.
- **Hard magnetic materials:** Retain their magnetism after the external field is removed. They are used for creating permanent magnets, such as those used in electric motors and generators.
- **Non-magnetic materials:** Not attracted to a magnet. Examples include wood, rubber, glass, and plastic.

- Ferromagnetic materials include the elements iron, nickel and cobalt and their alloys, some alloys of rare-earth metals
- The **rare-earth elements** (**REE**), also called **rare-earth metals**, or **rare earths**, are a set of 17 nearly indistinguishable lustrous silvery-white soft heavy metals. The 15 lanthanides (or lanthanoids),[a] along with scandium and yttrium, are usually included as rare earths. Compounds containing rare-earths have diverse applications in electrical and electronic components, lasers, glass, magnetic materials, and industrial processes.

- The term "rare-earth" is a misnomer, because they are not actually scarce, but because they are only found in compounds, not as pure metals, and are difficult to isolate and purify.
- They are relatively plentiful in the entire Earth's crust (cerium being the 25th-most-abundant element at 68 parts per million, more abundant than copper), but in practice they are spread thinly as trace impurities, so to obtain rare earths at usable purity requires processing enormous amounts of raw ore at great expense.

- Pure iron is not used for permanent magnets because it loses magnetism easily, while rare earth materials are used because their specific crystal structures, when alloyed with iron, lock magnetic domains in place, creating much stronger and more stable magnets.
- Rare earth elements, such as neodymium, allow the iron alloy to maintain its magnetization and resist being demagnetized by external fields.

- **Extraction and processing:** The extraction and refining of rare earth metals is an expensive and environmentally challenging process that can involve toxic waste and radioactive materials.
- **Geopolitical concentration:** The majority of rare earth element mining and processing is currently concentrated in China, leading to supply chain concerns for other nations.

Problems in DC motors

- The brushes needed for the commutator to work can malfunction and cause sparks, they must be regularly replaced and they lead to a loss in efficiency.