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Introduction to Computational Science and Engineering

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## 8.2.1 Models of time-dependent phenomena

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MO2.4

The mathematical models used to describe time-dependent phenomena in Nature and social systems are frequently **differential equations**, i.e., relationships between functions *and their derivatives*.

Where do models involving derivatives come from? The most important example is perhaps  $\vec{F} = m\vec{a}$ , Newton's second law, that we have already encountered. Here the basic quantity is the position  $\vec{x}(t)$  of a particle or an object as a function of time  $t$ . In general,  $\vec{x}(t) = (x_1(t), x_2(t), x_3(t))$  is a vector in 3 dimensions for each time  $t$ , but there are also cases where we only consider two, or one component of  $\vec{x}(t)$  at a time (and we might still denote those by  $x(t)$  when convenient). Then the velocity vector  $\vec{v}(t)$  is the time derivative of  $\vec{x}(t)$ , and the acceleration vector  $\vec{a}(t)$  is the time derivative of  $\vec{v}(t)$ :

$$\vec{v}(t) = \frac{d\vec{x}}{dt}(t), \quad \vec{a}(t) = \frac{d\vec{v}}{dt}(t) = \frac{d^2\vec{x}}{dt^2}(t).$$

(8.4)

The force vector  $\vec{F}$  acting on the object at  $\vec{x}(t)$  is either given as a function of time, or is itself a function of  $\vec{x}$  and/or  $\vec{v}$ . Either way, " $F = ma$ " becomes a differential equation.

More generally, mathematical models involving derivatives range from trustworthy elegant theories (like Newton's laws of gravity or Euler's equation of fluid

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