INERTIAL COORDINATE SYSTEM

In the article about apparent motion I wrote: "When a non-inertial coordinate system is used to map motion, then apparent motion is introduced. The apparent motion is the motion of the non-inertial coordinate system with respect to the inertial coordinate system." The definition of apparant motion I gave relies completely on distinction between the members of the equivalence class of inertial coordinate systems on one hand, and non-inertial coordinate systems on the other hand.

Definition:
If motion is mapped in an inertial coordinate system then Newton's laws of motion hold good.

Definition (formulated more generally):
If motion is mapped in any member of the equivalence class of inertial coordinate systems then Newton's laws of motion hold good.

Conversely: when the coordinate system that is used is in any way not an inertial coordinate system then additional terms are necessary in the equation of motion. These terms represent the acceleration of the coordinate system with respect to an inertial coordinate system. It's the laws of motion that point out which coordinate systems are inertial coordinate systems. Phrased more generally: the laws of motion single out the equivalence class of inertial coordinate systems.

Very often in discussions of the equivalence class of inertial coordinate systems the socalled fixed stars are invoked. In the next section I will argue that invoking the fixed stars is not a necessity.

What if the fixed stars would not have been visible?

What if our solar system would have been surrounded by a dense cloud of interstellar dust, so that the amount of stellar light that reaches the Earth is too small to be visible. In our history astronomers used the fixed stars as a reference for mapping celestial motions, and they attempted to find laws of celestial motion in terms of the motion with respect to the fixed stars. What if they would not have had that convenient reference system? Interestingly, while it would have been much harder to develop celestial mechanics it would not have been impossible.

Kepler came to conclusion that that the planets follow ellipse-shaped trajectories. (Actually, most of the planetary orbits are very close to circular. (Luckily for Kepler the planet he used to attack the problem of celestial motion, the planet Mars, has comparitively the largest eccentricity.) An ellipse has two foci, and in the case of the planetary orbits the line that connects the foci keeps pointing in the same direction relative to the fixed stars. Kepler's law of areas holds good if and only if the planetary motion is mapped relative to the fixed stars.

What if the fixed stars would not have been available? Hypothetically, what could Kepler have done then? The area law obtains if and only if the motion is mapped with respect to a coordinate system that does not rotate with respect to the line that connects the foci of the ellipse. But Kepler had no way of knowing that in advance. Kepler would have had to try a range of orientations of the coordinate system. In that form the problem may have been beyond Kepler's powers, but as science progresses at some point in history a genius would try his hand at a calculation of the area law for the case where the motion of Mars is mapped in a coordinate system in which Mars' orbit does not precess. Then the area law is obtained. The very fact that a law of motion obtains when motion is mapped in that particular way lends support to that particular choice of coordinate system.

Newton's refinements and unification of Kepler's laws could have been found without the guidance of the fixed stars. The added insight of Newton was to take uniformity of inertia as organizing principle. Newton showed that Jupiter is so heavy that the common center of mass of the Sun and Jupiter lies just outside the Sun. That is, rather than just assuming that the focus of Jupiter's ellipse-shaped orbit coincides with the center point of the Sun Newton applied the laws of motion to pinpoint the position of the focus. It is only when the motion of the planets is mapped in the coordinate system that is co-moving with the *center of mass* of the solar system that the laws of motion, such as the law of universal gravitation, hold good for*every celestial object*.

While the visibility of the fixed stars played a central role in the history of science as it happened to unfold for us, from a physics point of view the fixed stars as a *visual* reference for celestial motion are ultimately not necessary. Ultimately, all of the laws of planetary motion can be inferred from observing planetary*motion* only.

Observation of patterns in the motion itself suggest a common factor. All the planetary orbits are slightly eccentric. And these eccentricities *do not rotate relative to each other*, suggesting an underlying common factor. The coordinate system that is co-moving with the Solar system's common center of mass, and non-rotating with respect to the orbital eccentricities, is a coordinate system in which the laws of motion hold good; it's an inertial coordinate system.

Mutual dependence

There is an mutual dependence here that needs to be understood.
The equivalence class of inertial coordinate systems was intuited before Newton's laws of motion were formulated. Galilei argued that if we are on a boat that is cruising along with a constant velocity, moving along with perfect smoothness, then for an observer inside a cabin there is no experiment that will enable the observer to infer the velocity of the boat with respect to some permanent reference.
It was the recognition of the equivalence class of inertial coordinate systems that made

it possible to reach the level of understanding where Newton's laws of motion could be formulated.
As a need arises to provide an operational definition of the concept of inertial coordinate system, it is found that the only way to do that is to *invoke* Newton's laws of motion.

Proceeding as above may look like circular reasoning; it appears as if each concept, the equivalence class of inertial coordinate systems and the laws of motion, depend on prior establishment of the other concept in order to be derived. It looks like circular reasoning, but it isn't. Proof that the laws of motion are applicable is in the fact that the laws of motion are powerful tools: devices that are designed on the basis of the laws of motion perform according to the specifications. If the reasoning would be merely circular then it would not have any application in the real world.

The nature of physics laws

This is an illustration of the circumstance that it is inherently impossible to provide a justification of scientific theories on the basis of fundamental principles alone.

Comparison: the perception of electric resistance

The definition of the concept of electric resistance is Ohm's law: R = V/I . There is no such thing as first*defining* the physics of electric resistance, and then proceed to *discover* Ohm's law R = V/I.

There is no such thing as measuring electric resistance directly; the observables are current strength, I, and electromotive force, V. Also, in the early years of investigation of electrics there were a number of different ways in usage of how to gage electromotive force, and none of them was the same as the modern one. The modern way of gaging electromotive force is designed to be as linear as possible, but in the early days there was no way of knowing which of the methods was linear and which wasn't. However, it was noticed that with some definitions of electromotive force Ohm's law obtained, and with other definitions it didn't (or with much more deviation from the law). This had an influence on how the concept of electromotive force was defined: the scientists came to favor definitions of electromotive force for which Ohm's law obtained.

So, is Ohm's law just circular reasoning? No, it isn't. Over time it became increasingly clear that a material's electric resistance can be predicted on the basis of its structural properties alone. Metals are good conductors because the outer electrons of the metal atoms are not really bound to the individual atoms. Rather, the metal contains a large population of electrons that are so free that they can flow through the metal like a fluid or a gas.

Historically, Ohm's law was intuited on the basis of very little evidence, and subsequently Ohm's law influenced the way that the concept of electromotive force was defined. Over time Ohm's law grew from strength to strength, gaining support in ways that were entirely independent from its first conception.

Returning to theory of motion, this aspect of the endeavour of physics is discussed in the book 'Gravitation' by Misner, Thorne en Wheeler (paragraph 12.3)

Point of principle: how can one write down the laws of gravity and properties of spacetime first (paragraph 12.1) and only afterward (here) come to grip with the nature of the coordinate system and its nonuniqueness? Answer: (a quotation from paragraph 3.2, slightly modified) "Here and elsewhere in science, as emphasized not least by Henri Poincaré, that view is out of date which used to say: 'define your terms before you proceed'. All the laws and theories of physics, including Newton's laws of gravity, have this deep and subtle character that they both define the concepts they use (here Galilean coordinates) and make statements about these concepts"

Contrariwise, the absence of some body of theory, law and principle deprives one of the means properly to define or even use concepts. Any forward step in human knowlege is truly creative in this sense: that theory concept, law, and measurement —forever inseparable—are born into the world in union.

Source : http://www.cleonis.nl/physics/phys256/inertial_coordinate_system.php