Rules of Plate Motion on a Plane

- Rule #2: Subduction is asymmetric.
- Rule #3: The relative motion of two plates at a transform fault is parallel to that fault.

(*note: there are always exceptions to these simplified rules)
Relative Velocity Vectors

- The velocity of a first plate (A) relative to a second (B) = the vector velocity of the first plate (A) minus the vector velocity of the second (B).

Figure 9.3. Different cases of two plates spreading from a ridge in which velocities are measured from different references. The plates have the same relative velocities in all four cases.

Figure 9.4. (a) Plots of the velocities of the plates for each case in Figure 9.3. (b) The same velocities referred internally to each other, rather than to an external origin.
Relative Velocity Vectors

Figure 9.5. Relative velocities at a trench. The two possible trench polarities are shown (a, b), depending on which plate is being consumed. In each case, the top panel shows a cross-section, the middle panel shows a map view, and the bottom panel shows the velocity diagram.
Plate Margin Migration

- Relative plate velocities determine the evolution of plates and the migration of plate margins.
- Note: Boundaries move WRT each other!

Figure 9.6. Different relative motions of ridges and trenches.
Plate Evolution Sequences

- Plates - they grow, they shrink, they morph.
How to determine their fates:

Figure 9.7. A plate evolution sequence showing the development with time of case (d) of Figure 9.6. The grey lines are former features on plate B that have been overridden by plate C.

Figure 9.8. Sequence showing the evolution of a ridge with a transform fault offsetting it.
Plate evolution in the real world

Figure 9.7. A plate evolution sequence showing the development with time of case (d) of Figure 9.6. The grey lines are former features on plate B that have been overridden by plate C.
Plate Motions on a Sphere

- Euler’s Theorem: motion of any spherical cap (plate) can be described by a single rotation about a suitably chosen axis passing through the center of the Earth.

Motion of Plate “A” can be described by rotation about \(A\omega\).

By convention, positive rotation is counterclockwise viewed above \(A\omega\).

Can specify \(A\omega\) as \((\omega_x, \omega_y, \omega_z)\) or (lat, long, rate), where lat, long are point where \(A\omega\) exits Earth and rate is deg/my.
Relative Plate Motions

- $A\omega_B = \text{Relative motion between plates A,B given by:}$

  $$A\omega_B = A\omega - B\omega$$

  (motion of A with respect to fixed B)

![Diagram showing relative plate motions](image)
In general, we don’t know either $A\omega$ or $B\omega$, but can get $A\omega_B$ from:

- Orientation of ridge (points toward pole $A\omega_B$)
- Transforms are small circles about $A\omega_B$
- Distance of magnetic stripes from ridge (gives $|\omega| = \text{rate}$)
- Direction of EQ slip at trench
Instantaneous Relative Motions ...

- Instantaneous motions are vectors, and can be added as vectors:
  - \[ A \omega_B = - B \omega_A \]
  - \[ A \omega_B + B \omega_C = A \omega_C \quad \text{... you can find the relative motion between any two plates (even if they don’t share a boundary)} \]
  - \[ A \omega_B - C \omega_B = A \omega_C \]
  - \[ A \omega_B + B \omega_C + C \omega_A = A \omega_A = 0 ! \]
Velocity of Points on a Sphere

- If $\omega$ describes how a plate is moving, then a point $r (r_x, r_y, r_z)$ on the plate has velocity $v (v_x, v_y, v_z)$ given by:

$$ v = \omega \times r = \begin{vmatrix} i & j & k \\ \omega_x & \omega_y & \omega_z \\ r_x & r_y & r_z \end{vmatrix} $$
Absolute Plate Motion

- In all cases above, relative motion $\omega_A - \omega_B$ is the same.
- For Absolute Motion, we assume that there is some fixed reference frame for the Earth.
- One possibility is fixed Hot Spots. Others are no net rotation, minimum net torque, etc. All turn out similar.

Figure 9.3. Different cases of two plates spreading from a ridge in which velocities are measured from different references. The plates have the same relative velocities in all four cases.
Hot Spot Reference Frame

- Works OK, but Hot Spots move (slowly) with respect to each other.
- Number of Hot Spots subject to debate
Triple Junctions

- Goals of triple junction study:
  - to graphically represent triple junctions and their corresponding vector diagrams.
  - to determine triple junction stability and the conditions under which that stability can be attained.
  - to make certain predictions based on the nature of plate margins and relative plate velocities.
Triple Junctions

- **Def:** A point at which three plate margins meet.
- **Three possible margin types:**
  1. Transform fault (F)
  2. Ridge (R)
  3. Trench (T)
Start with the simplest, most ideal, ridge-ridge-ridge triple junction:

Figure 9.9. (a) and (b) Evolution of a ridge–ridge–ridge (RRR) triple junction. (c) Velocity diagram showing the three plate velocities, the three ridge velocities and the triple junction velocity (J). The ridges must lengthen into the triangle (abc) in (b).
Box 2-9. (continued)
Triple Junctions

- Goals of triple junction study:
  - to graphically represent triple junctions and their corresponding vector diagrams.
  - to determine triple junction stability and the conditions under which that stability can be attained.
  - to make certain predictions based on the nature of plate margins and relative plate velocities.
Vector Diagrams

- Step 1: Pretend to stand on one plate. Mark and label that plate with a point and a letter.
- Step 2: Determine the motion of one of the two remaining plates relative to the plate you’re standing on. Draw a vector arrow from the point representing its relative velocity. At the end of that arrow, mark and label that plate with another point.
- Step 3: Pretend to now stand on the new point and draw another arrow representing the relative velocity of the third plate. Mark and label the third plate with a point and draw an arrow connecting it to the first point.
Vector Diagrams continued

- Where to put the triple junction:
  - If the margin between plates A and B is a trench, draw a dashed line parallel to the trend of the trench that passes through the point representing the overriding plate.
  - If the margin between plates A and B is a transform fault, draw another dashed line along the line $ab$ of the vector triangle.
  - If the margin between plate A and B is a ridge, draw a dashed line perpendicular to, and bisecting, the line $ab$. 
Representing plate margins
Cox and Hart, 1986

Triple junctions migrate along the boundaries between pairs of plates as if they are marbles rolling parallel to the boundaries. A marble (or triple junction) will remain on a plate boundary if it has a velocity corresponding to any point on the dashed velocity line $ab$.

The velocity line $ab$ for a trench is parallel to the trench and, because the trench moves with the overthrust plate, it passes through the point in velocity space representing the overthrust plate. This relationship does not require that the direction of convergence be perpendicular to the trench.

The velocity line $ab$ for a transform is parallel to the transform and, because the transform doesn’t move with respect to either plate, it lies along the line through both $A$ and $B$ showing the relative velocity of plates $A$ and $B$.

The velocity line $ab$ for the ridge is parallel to the ridge. If spreading is symmetrical and perpendicular to the trend of the ridge (as shown in this example), then $ab$ is the perpendicular bisector of the line segment $AB$ showing the relative velocity of plates $A$ and $B$. 
Triple Junctions

- Goals of triple junction study:
  - to graphically represent triple junctions and their corresponding vector diagrams.
  - to determine triple junction stability and the conditions under which that stability can be attained.
  - to make certain predictions based on the nature of plate margins and relative plate velocities.
Triple Junction Stability

- The lines that were drawn on the vector diagram showing plate margins must meet at a point for the triple junction to be stable.
Stability conditions
Cox and Hart, 1986
Triple Junctions

- Goals of triple junction study:
  - to graphically represent triple junctions and their corresponding vector diagrams.
  - to determine triple junction stability and the conditions under which that stability can be attained.
  - to make certain predictions based on the nature of plate margins and relative plate velocities.
Predictions

- What will happen to plates A, B, and C over time?
- What will happen to their margins?
- What will happen to the triple junction?

Figure 9.9. (a) and (b) Evolution of a ridge–ridge–ridge (RRR) triple junction. (c) Velocity diagram showing the three plate velocities, the three ridge velocities and the triple junction velocity (J). The ridges must lengthen into the triangle (abc) in (b).