Omnidirectional Drive Systems

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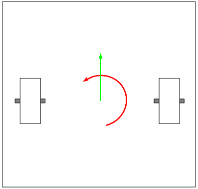
Ian Mackenzie

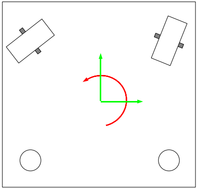
- Involved in FIRST since 1998
- High school student on Woburn Robotics (188) from 1998-2001
- University mentor for Woburn Robotics in 2002
- Recruiter/organizer for FIRST Canadian Regional in 2003
- Lead mentor for Simbotics (1114) in 2004, created SimSwerve crab drive system
- Planning committee/head referee for Waterloo Regional in 2005 and 2006
- Scheduling algorithm developer, inspector, Lego League referee. . .

Introduction

- Tank drive: 2 degrees of freedom



- Omnidirectional drive: 3 degrees of freedom



Advantages and Disadvantages

Advantages

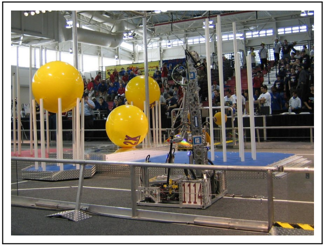
- Maneuverability

Disadvantages

- Complex
  - Heavy
  - Less robust
  - Tricky to control
- (Usually) less pushing force

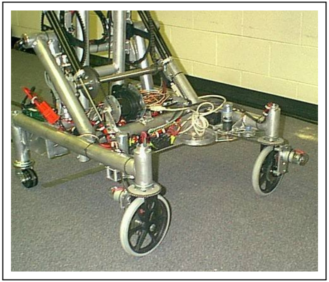
Strategies Favouring Omnidirectional Drive

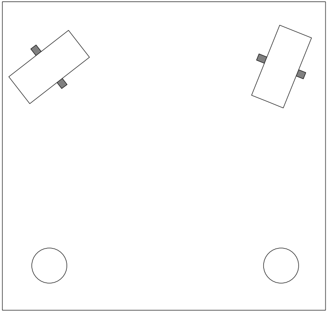
- Primarily offensive robots
  - Not good at pushing others
  - Good at avoiding defense
  - If implemented correctly, easier to align robot to targets (e.g. balls to pick up, goals to score into)
- Confined spaces on the field
  - *Raising the Bar* in 2004
  - Analogous to industrial applications



Swerve Drive

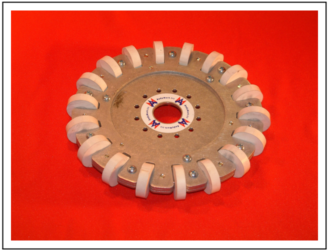
- Independently steered drive modules
- Simple conceptually
- Simple wheels
- Good traction
- Complex to build
- Complex to program and control
- Maximum pushing force
- Either steered gearboxes or concentric drive

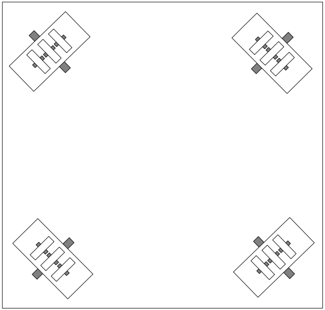




Holonomic Drive

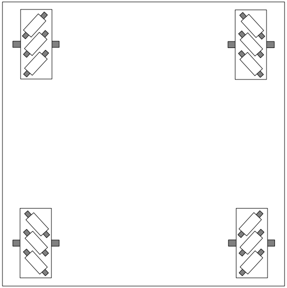
- Wheels with ‘straight’ rollers (omniwheels)
- More complex conceptually
- Fairly complex wheels
- Fairly simple to build
- Simple to control
- Lower traction
- Less speed and pushing force on when moving diagonally





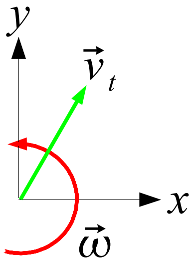
Mecanum Drive

- Wheels with angled rollers
  - NOTE: In the diagram, imagine you are viewing the wheels from above, but the top half of the wheels are transparent so you are seeing the pattern of contact between the wheels and the ground
- Very complex conceptually
- Very complex wheels
- Otherwise simple to build
- Simple to control
- Less speed and pushing force when moving diagonally



Kinematics

- Mathematics describing motion
- Solid grasp of theory makes control much easier
- Great example of how real university-level theory can be applied to FIRST robots
- Three step process:
  - Define overall robot motion
    - Usually by $\vec{v}_t$, $\vec{\omega}$; can transform other forms into this form quite easily
  - Calculate velocity at each wheel
  - Calculate actual wheel speed (and possibly orientation) from that velocity



Single Wheel

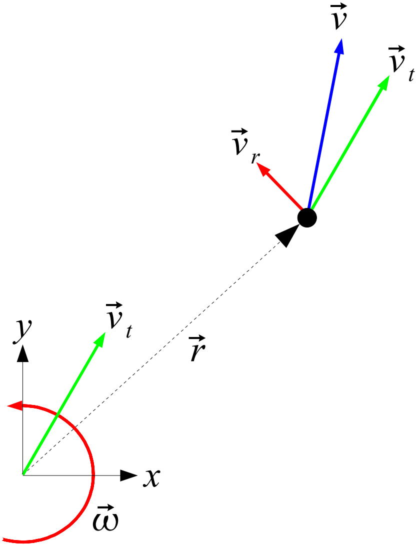
Common to all types of omnidirectional drive

Vector approach

$$\vec{v} = \vec{v}_t + \vec{\omega} \times \vec{r}$$

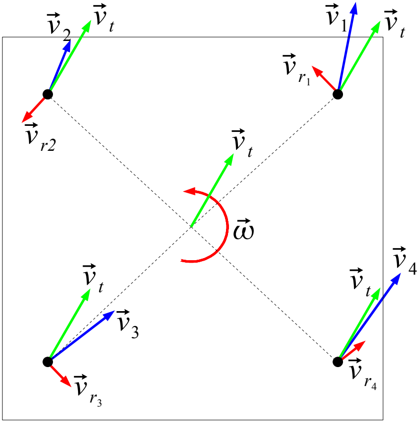
Scalar approach

$$v_x = v_{t_x} - \omega \cdot r_y$$
$$v_y = v_{t_y} + \omega \cdot r_x$$



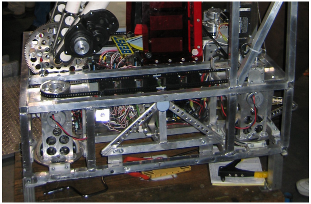
Entire base

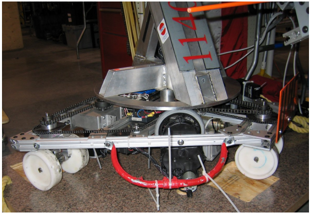
- In general, each wheel will have a unique speed and direction
    - Full swerve drive would require at least 8 motors; has been done once (Chief Delphi in 2001)
    - Swerve drive usually done with 2 swerve modules along with casters or holonomic wheels



Swerve Drive Approximations

- Some drive trains use swerve modules steered together
  - Four modules steered together (crab drive)
  - Front modules steered together, back modules steered together
  - Right modules steered together, left modules steered together
- Does not allow full freedom of motion
- Requires fewer steering motors

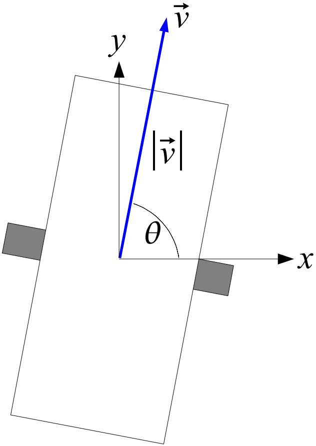




Swerve Drive

- Resolve velocity at each wheel into magnitude and angle
- Be careful with angle quadrant!

$$|\vec{v}| = \sqrt{v_x^2 + v_y^2}$$
$$\theta = \arctan\left(\frac{v_y}{v_x}\right)$$



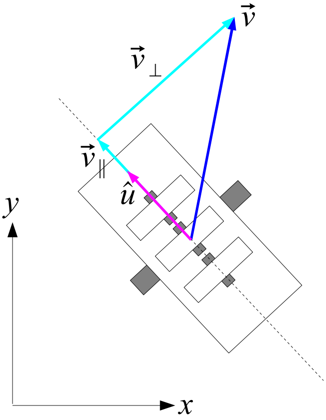
Holonomic Drive

- Resolve velocity into parallel and perpendicular components

$$
\begin{aligned}
\left|\vec{v}_{\parallel}\right| &= \vec{v}\cdot\hat{u} \\
&= (v_x\hat{\imath} + v_y\hat{\jmath})\cdot \\
&\quad \left(-\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}\right) \\
&= -\frac{1}{\sqrt{2}}v_x + \frac{1}{\sqrt{2}}v_y
\end{aligned}
$$

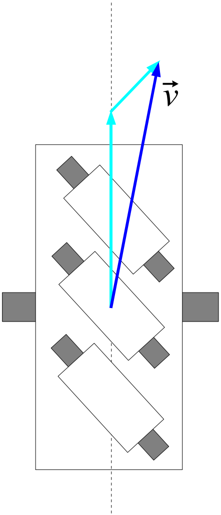
- Magnitude of $\vec{v}_{\parallel}$ gives wheel speed

$$
\begin{aligned}
\left|\vec{v}_w\right| &= \left|\vec{v}_{\parallel}\right| \\
&= -\frac{1}{\sqrt{2}}v_x + \frac{1}{\sqrt{2}}v_y
\end{aligned}
$$



Mecanum Drive

- NOTE: As before, imagine viewing the wheel with the top half transparent; the diagram shows the pattern of contact between the wheel and the ground
- Similar to holonomic drive
- Conceptually: Resolve velocity into components parallel to wheel and parallel to roller
- Not easy to calculate directly (directions are not perpendicular), so do it in two steps

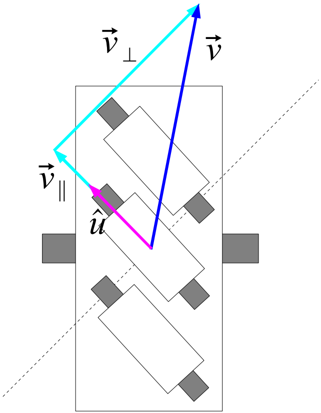


Resolve to Roller

- Resolve velocity into components parallel and perpendicular to roller axis
- Perpendicular component can be discarded

$$
\begin{aligned}
\left|\vec{v}_{\parallel}\right| &= \vec{v} \cdot \hat{u} \\
&= (v_x \hat{\imath} + v_y \hat{\jmath}) \cdot \\
&\quad \left(-\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}\right) \\
&= -\frac{1}{\sqrt{2}} v_x + \frac{1}{\sqrt{2}} v_y
\end{aligned}
$$

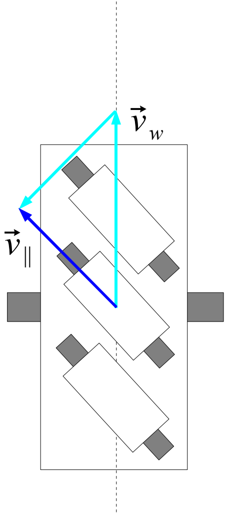
- $\hat{u}$ is not the same for each wheel!



Resolve to Wheel

- Use component parallel to roller axis and resolve it into components parallel to wheel and parallel to roller
- This does not involve simple projections like holonomic drive, so we cannot use dot products
- However, angle is known, so we can calculate $|\vec{v}_w|$ directly:

$$
\begin{aligned}
|\vec{v}_w| &= \frac{|\vec{v}_{\|}|}{\cos 45^\circ} \\
&= \sqrt{2}\left(-\frac{1}{\sqrt{2}}v_x + \frac{1}{\sqrt{2}}v_y\right) \\
&= -v_x + v_y
\end{aligned}
$$

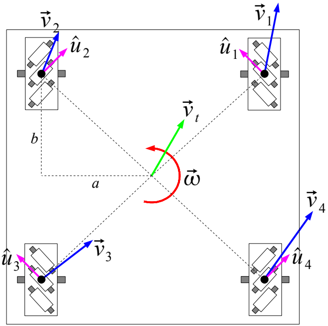


Mecanum Drive Example

Using wheel 3 as an example:

$$
\begin{aligned}
v_{3_x} &= v_{t_x} + \omega b \\
v_{3_y} &= v_{t_y} - \omega a \\
\hat{u}_3 &= -\frac{1}{\sqrt{2}}\hat{\imath} + \frac{1}{\sqrt{2}}\hat{\jmath}
\end{aligned}
$$

$$
\begin{aligned}
|\vec{v}_{w_3}| &= \sqrt{2}\left(-\frac{1}{\sqrt{2}}v_{3_x} + \frac{1}{\sqrt{2}}v_{3_y}\right) \\
&= -v_{3_x} + v_{3_y} \\
&= -v_{t_x} - \omega b + v_{t_y} - \omega a \\
&= v_{t_y} - v_{t_x} - \omega\,(a+b)
\end{aligned}
$$

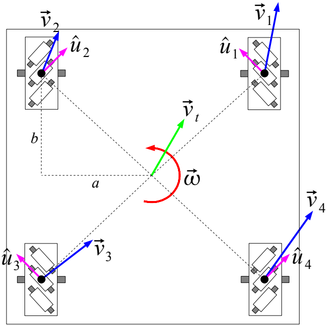


Mecanum Drive Example

Similarly,

$$\begin{aligned} |\vec{v}_{w1}| &= v_{t_y} - v_{t_x} + \omega\,(a+b) \\ |\vec{v}_{w2}| &= v_{t_y} + v_{t_x} - \omega\,(a+b) \\ |\vec{v}_{w4}| &= v_{t_y} + v_{t_x} + \omega\,(a+b) \end{aligned}$$

Note that all speeds are linear functions of the inputs (i.e. no trigonometry or square roots necessary), so control is very fast.

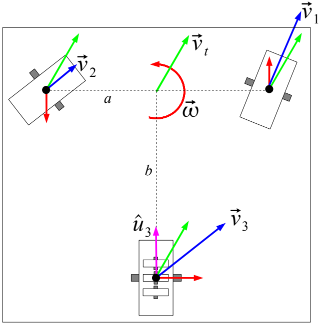


Hybrid Swerve/Holonomic Drive

$$
\begin{aligned}
v_{1_x} &= v_{t_x} \\
v_{1_y} &= v_{t_y} + \omega a
\end{aligned}
$$

$$
\begin{aligned}
v_{2_x} &= v_{t_x} \\
v_{2_y} &= v_{t_y} - \omega a
\end{aligned}
$$

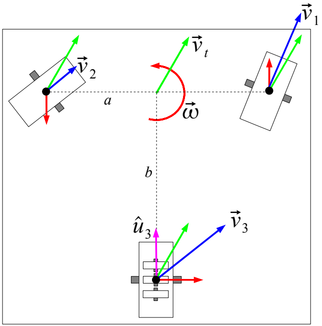
$$
\begin{aligned}
v_{3_x} &= v_{t_x} + \omega b \\
v_{3_y} &= v_{t_y}
\end{aligned}
$$



Hybrid Swerve/Holonomic Drive

Swerve module 1:

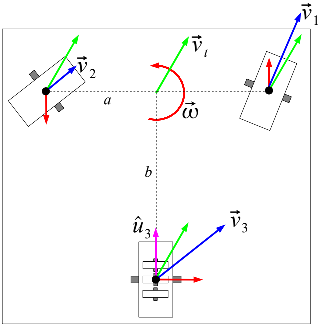
$$
\begin{aligned}
|\vec{v}_{w_1}| &= \sqrt{v_{1_x}^2 + v_{1_y}^2} \\
&= \sqrt{v_{t_x}^2 + \left(v_{t_y} + \omega a\right)^2} \\
\theta_1 &= \arctan\left(\frac{v_{1_y}}{v_{1_x}}\right) \\
&= \arctan\left(\frac{v_{t_y} + \omega a}{v_{t_x}}\right)
\end{aligned}
$$



Hybrid Swerve/Holonomic Drive

Swerve module 2:

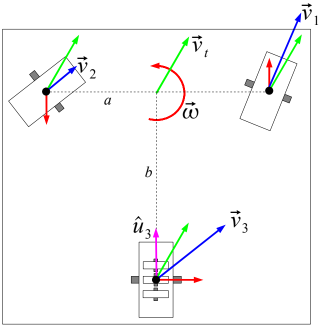
$$
\begin{aligned}
|\vec{v}_{w_2}| &= \sqrt{v_{2_x}^2 + v_{2_y}^2} \\
&= \sqrt{v_{t_x}^2 + \left(v_{t_y} - \omega a\right)^2} \\
\theta_1 &= \arctan\left(\frac{v_{2_y}}{v_{2_x}}\right) \\
&= \arctan\left(\frac{v_{t_y} - \omega a}{v_{t_x}}\right)
\end{aligned}
$$



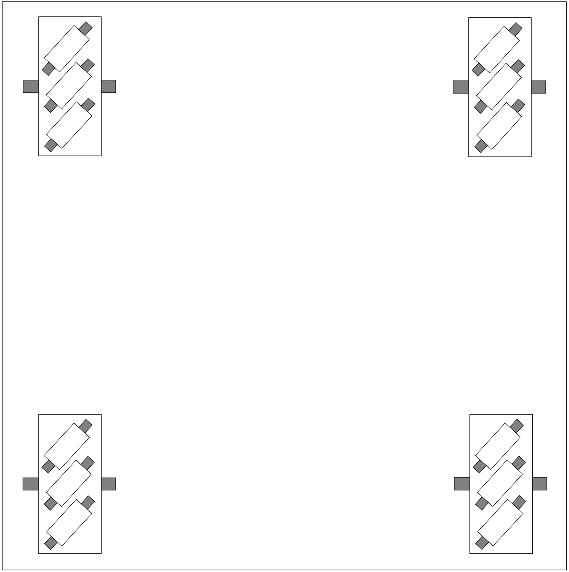
Hybrid Swerve/Holonomic Drive

Holonomic wheel:

$$\begin{aligned} |\vec{v}_{w_3}| &= \vec{v}_3 \cdot \hat{u}_3 \\ &= \left(v_{3_x}\hat{\imath} + v_{3_y}\hat{\jmath}\right) \cdot \hat{\jmath} \\ &= v_{3_y} \\ &= v_{t_y} \end{aligned}$$

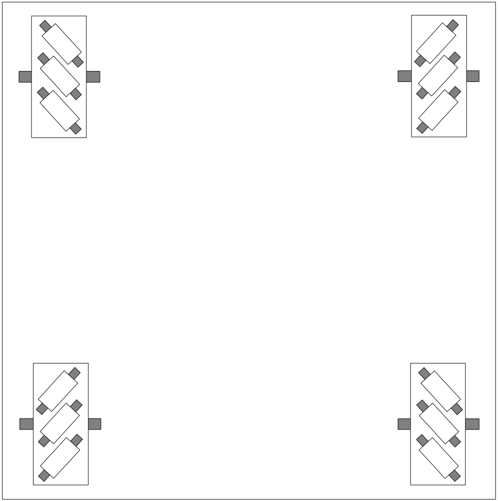


What's Wrong With This Picture?



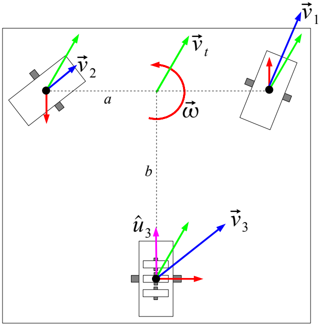
What's Wrong With THIS Picture?

NOTE: Remember that diagrams show the pattern of wheel contact with the ground



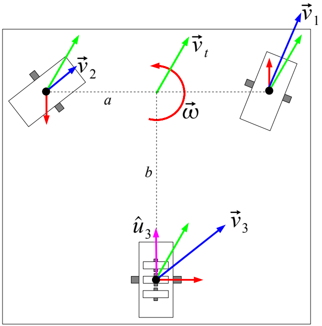
Scaling Issues

- Speed calculations may result in greater-than-maximum speeds
- Possible to limit inputs so this never happens, but this overly restricts some directions
- Better to adjust speeds on the fly



Scaling Algorithm

- Calculate wheel speeds for each wheel
- Find maximum wheel speed
- If this is greater than the maximum possible wheel speed, calculate the scaling factor necessary to reduce it to the maximum possible wheel speed
- Scale all wheel speeds by this factor



Robots to Check Out

Team 148 in Curie has mecanum drive with two control modes; tank steering and full 3 degree of freedom steering

Team 16 in Galileo has two swerve modules steered together but driven seperately at the front, and then a third swerve module at the back; drive is either in crab mode or tank mode

Team 71 in Newton has 4 swerve modules steered together but powered seperately, driven in a hybrid crab/tank system

Team 118 in Newton has 4 swerve modules steered *and* driven together (pure crab steering)

Team 830 in Galileo has a pure holonomic drive system with full 3 degree of freedom motion

References I

Swerve

- SimSwerve: http://www.chiefdelphi.com/media/papers/1552
- Swerve module: http://www.chiefdelphi.com/forums/showthread.php?t=46817
- Concentric crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=24135
- Concentric drive: http://www.chiefdelphi.com/forums/showthread.php?t=23034
- Concentric crab module: http://www.chiefdelphi.com/forums/showthread.php?t=22708
- Concentric crab drive: http://www.chiefdelphi.com/media/photos/16091
- Swerve module: http://www.chiefdelphi.com/forums/showpost.php?p=195859&postcount=3

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- Concentric lego crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=22552
- Swerve drive approximations: http://www.chiefdelphi.com/forums/showthread.php?t=22386
- Concentric crab module: http://www.chiefdelphi.com/forums/showthread.php?t=20242
- Crab drive steering: http://www.chiefdelphi.com/media/papers/1599
- Lego crab drive: http://www.chiefdelphi.com/forums/showthread.php?t=28251
- Swerve drive approximations: http://www.chiefdelphi.com/forums/showthread.php?t=28195

References III

- Team 111 (2003): http://www.wildstang.org/gallery2/v/2003/2003_Build/2003_Robot_Build/2003_Robot_Proto/
- Team 114 (2005): http://engineer.la.mvla.net/robotics/images.php?showCollection=2005%20Inventor
- Crab drive base: http://www.chiefdelphi.com/media/photos/22005
- Swerve with unpowered omni wheels: http://www.chiefdelphi.com/media/photos/14646
- Crab module: http://www.chiefdelphi.com/media/photos/14556

Mecanum

- Mecanum drive: http://robotics.ee.uwa.edu.au/eyebot/doc/robots/omni.html
- Airtrax: http://www.airtrax.com

References IV

- (Even more) complex Mecanum wheels: http://www.chiefdelphi.com/forums/showthread.php?t=39885
- Mecanum wheel design: http://www.chiefdelphi.com/forums/showthread.php?t=46175
- Mecanum wheel: http://www.chiefdelphi.com/media/photos/22128
- Mecanum drive: http://www.chiefdelphi.com/media/photos/20664

Holonomic

- AndyMark: http://www.andymark.biz/
- Omni tracks: http://www.chiefdelphi.com/forums/showthread.php?t=46501
- Tilted omniwheels: http://www.chiefdelphi.com/forums/showthread.php?t=41723

References V

- Omniwheel position: http://www.chiefdelphi.com/forums/showthread.php?t=38839
- Holonomic drive: http://www.chiefdelphi.com/forums/showthread.php?t=28168
- Holonomic drive: http://www.chiefdelphi.com/media/photos/22831
- Holonomic drive: http://www.chiefdelphi.com/media/photos/22800
- Dual omniwheel: http://www.chiefdelphi.com/media/photos/21966
- Advanced omniwheels: http://www.chiefdelphi.com/media/photos/19483

General

- Steering control: http://www.chiefdelphi.com/forums/showthread.php?t=27022

References VI

- General discussion: http://www.chiefdelphi.com/forums/showthread.php?t=20434
- Strategies: http://www.chiefdelphi.com/forums/showthread.php?t=45967
- Good general discussion: http://www.chiefdelphi.com/forums/showthread.php?t=20434

Questions?

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- “Ian Mackenzie” on Chief Delphi