Automobile Steering
Land & Lee (1994)

Where do we look when we steer

Eye movements of three subjects while driving a narrow dirt road with tortuous curves around Edinburgh Scotland.

Geometry demanded almost continuous visual guidance and very slow driving speeds.

Very special case
Interesting...but how generalizable?
Frame-by-frame Video Analysis

Note inverted image of eye in lower-third of video; and, two reference “tape marks” on windshield to allow head tracking computation.
Land & Lee (1994) video clip
The graphs show the gaze angle and steering angle over time for two individuals, M.L. and J.C., respectively.

- **M.L.**
  - Gaze angle: Fluctuations in the upper graph indicate changes in gaze direction.
  - Steering angle: The lower graph shows the corresponding steering adjustments.

- **J.C.**
  - Gaze angle: Noticeable changes in gaze direction are observed.
  - Steering angle: Corresponding steering adjustments are evident in the lower graph.

The y-axis labels represent degrees, with positive values indicating rightward gaze or steering, and negative values indicating leftward gaze or steering.

**Time (s)**: The x-axis represents time in seconds, with a total of 60 seconds shown for each graph.
Fixation Density Distributions

Fixations cluster around the near “tangent point” on left curves

Fixations cluster around a fixed “preview distance” on straight roadway segments

Oversampling of “tangent point” Replicated for right curves
Gaze and Steering Angle Correlation

Drivers tend to look to the future path of travel
Gaze angle correlates with steering wheel angle
when “lag time” is adjusted (i.e., gaze leads motor control)
Land & Lee (1994) conclusions...

• “tangent point” provides reliable information about the curvature of upcoming bend

\[ \text{curvature} = \frac{1}{\text{radius}} = \frac{\theta^2}{2d} \]

\( \theta \) = angle from current heading
\( d \) = distance of driver’s head from inner lane edge

• Drivers monitor both \( \theta \) and \( d \) cues (parameters) simultaneously (see Land & Horwood, 1995)
Tangent Point Geometry

Recovering roadway “curvature”

Curvature = \( \frac{1}{r} \)

\( r \) = radius of curved path of travel
\( \theta \) = heading-to-tangent angle
\( d \) = distance to near edge line

\( \cos(\theta) = \frac{(r-d)}{r} \)

and since \( \cos(\theta) \approx \theta^2/2 \)

the equation above becomes

\( \theta^2/2 = \frac{(r-d)}{r} \)

which reduces to

\( \theta^2/2d = \frac{1}{r} = \text{roadway curvature} \)

Q: Where would you look if you wanted to obtain the farthest possible preview time (or distance) of the future path of travel
   A: see 🌟
Land’s Dual-Cue Approach

(Optimal Straight Road Steering)

Vanishing Point

Heading/Position Vector

Preview Distance Transect (10-30m)

1 : 2.5 Transect Intercept Ratio
(Lane Position Cue)

Splay Angle(s)
(Course Heading Cue)

30°  55°
Land’s Dual-Cue Approach

(Departure from Optimal Heading)

Veering to Right (Scenario B)
Heading diverges from vanishing point; Intersect of preview distance transect is now highly biased to the left; Encroachment into oncoming lane is imminent.

Veering to Left (Scenario C)
Lane departure into shoulder is imminent.

What other cues are available here?
Optical flow information?
TLC?
Land’s Dual-Cue Approach
(Correct Heading but Improper Lane Position)

Lane position is biased to the right.

Lane position is biased to the left.
Land’s Cues are Ambiguous in Isolation
(but not in combination)

Bisection of the preview distance transect is an ambiguous indicator of lane keeping maintenance until considered together with long-range heading information.

Land and Horwood (1995) demonstrate the separate roles for near-range lane position information and far-range heading angle cues using their selective visual sampling paradigm.
Fig. 7.9 Performance on a simulator when different 1° vertical segments of a winding road were visible (a-c, top). Records show curvature of road and car’s track, and position of car relative to the midline of the road. Inaccuracies – discrepancies between the road and car track – show up in black. More distant parts of the road (a) allow road curvature to be matched accurately but are very poor at keeping the car in lane. Near regions (c) are better for maintaining lane position but cause the steering to go into ‘bang-bang’ mode. From Land and Horwood (1995).
Land & Horwood (1995)
Perceived road curvature estimated from far distance visual information using open-loop decision-making processes versus current lane position maintenance via closed-loop nulling of error signals based upon near distance visual information.
Rather than estimating curvature or other complex entities, the 2-point model relies solely upon directly perceivable visual input.

The **near point** is the center of the lane at some nearby distance and is used to monitor both lateral position and stability (central or peripheral vision).

**Far point** can be ANY salient point that provides predictive steering angle information about upcoming changes in roadway geometry (anticipatory; smoothness; minimizes “lag” effects).

**Potential FAR POINTS**: vanishing point; tangent point; lead vehicle
Salvucci & Gray (2004)

Two-Point Computational Model of Steering

\[ \Delta \phi = k_f \Delta \theta_f + k_n \Delta \theta_n + k_i \theta_n \Delta t \]

Steering Angle = Far point stability + Near point stability + Near point centering
Simulating Land & Horwood (1995)
Experimental Viewing Conditions

Move-Near

Move-Far

Move-Both
Salvucci & Gray (2004)

Two-Point Model of Steering

(a) Human Data

(b) Model Simulations
Model Mimics Human Behavior in Far-Only vs. Near-Only Viewing

(a) Far-Only Vision
Lane keeping highly biased while negotiating curves

(b) Near-Only Vision
Good average lane position but “Bang-bang” instability
Gaze scanning moves to destination lane prior to lane change (Salvucci & Liu, 2002).

Large initial movement followed by shallow movement “return phase”.

Model (like humans) switches from using near/far points of current lane to near/far points in the destination lane.

Wallis et al. (2002) failure to execute “return phase” after lane change in no visual Feedback condition (Just-in-Time visual cognition rather than open loop?)
Pure Open-Loop Steering
(A Thought Experiment)

• Image that your driving down the right lane of a freeway with your hands fixed to an imaginary steering wheel

• Now, execute an imaginary lane change into the adjacent left lane...complete with your steering inputs to the imaginary steering wheel

• Describe your inputs to the steering wheel
Wallis, et al. (2002)

Steering Maneuver
With Visual Feedback

Steering Maneuver
Imagined or Without
Visual Feedback
Normal Steering Profile
Steering Paths without Visual Feedback

Plots of lane change maneuvers completed in the dark (i.e., after entering a tunnel)

Participants consistently fail to execute the “return” input to the steering wheel.
Effects of Providing Post-Maneuver Visual Feedback of Heading Error

Single subject repeatedly omits “return phase” steering response in the dark condition with no end-of-maneuver feedback

Single subject quickly learns to correct omission error when terminal heading error is provided
Myers’ USD Thesis Project

• Modified visual occlusion paradigm (near-only; far-only; full vision baseline)

• Prediction:
  Time-to-line-crossing (TLC) unchanged in FAR condition but degraded in NEAR condition

SD Lane Position unchanged in NEAR but degraded in FAR condition

• TLC = far process; SD Lane Pos. = near process