Sensitivity Analysis for Digital Accessibility Index

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1 Explanation of Sensitivity Analysis in the DigitalAccessibilityIndex Class

The sensitivity analysis in the `validate_weights` method of the `DigitalAccessibilityIndex` class assesses how robust the Digital Accessibility Index (DAI) scores are to small changes in the parameter weights. Below is a detailed breakdown of how it works and why it is important.

1.1 How Sensitivity Analysis Works in the Class

1. **Purpose**: Sensitivity analysis tests how changes in the weights (derived from PCA or provided by experts) affect the DAI scores. This helps evaluate whether the index is overly sensitive to specific parameters, which could indicate instability or over-reliance on certain factors.
2. **Implementation in the Code**:
   - The method perturbs each parameter's weight one at a time by increasing it by 10% (`temp_weights[param] *= 1.1`).
   - After perturbing a weight, the weights are re-normalized to sum to 1 to maintain consistency (`temp_weights = {p: w / sum(temp_weights.values()) for p, w in temp_weights.items()}`).
   - The DAI is recalculated using the perturbed weights (`temp_dai`), and the mean absolute difference between the original DAI scores and the perturbed DAI scores is computed (`np.mean(np.abs(temp_dai - original_dai))`).
   - This process is repeated for each parameter, and the results are stored in a dictionary (`sensitivity`) that maps each parameter to its corresponding mean absolute change in DAI scores.
3. **Output**: The `sensitivity` dictionary in the `validation_results` shows the average change in DAI scores for each parameter when its weight is perturbed. For example, if perturbing the weight of "Internet_Access" results in a mean absolute change of 0.02, it indicates that the DAI scores change by an average of 0.02 units when the weight of "Internet_Access" is increased by 10%.

1.2 Why Sensitivity Analysis is Important

1. **Robustness of the Index**: Sensitivity analysis ensures that the DAI is stable and not overly dependent on any single parameter. If a small change in one parameter's weight causes a large change in the DAI scores, it suggests that the index might be unreliable or overly sensitive to that parameter. This could lead to misleading conclusions about digital accessibility.
2. **Validation of Weights**: The weights (whether derived from PCA or provided by experts) are critical to the DAI calculation. Sensitivity analysis helps validate whether the chosen weights produce consistent and reliable results. If the index is highly sensitive to small weight changes, it may indicate that the weights need further refinement or that additional parameters should be considered.
3. **Transparency and Trust**: By quantifying how much the DAI changes with weight perturbations, the analysis provides transparency to stakeholders (e.g., policymakers, researchers) about the reliability of the index. This builds trust in the system, especially when used for decision-making, such as prioritizing villages for digital infrastructure investments.
4. **Identifying Key Parameters**: Sensitivity analysis highlights which parameters have the most influence on the DAI. For example, if perturbing the weight of "Internet_Access" causes a larger change in DAI scores compared to "Internet_Banking," it suggests that "Internet_Access" is a more critical driver of the index. This can guide policy interventions by focusing on high-impact parameters.
5. **Handling Uncertainty**: In real-world scenarios, weights may be subject to uncertainty (e.g., due to subjective expert judgment or variability in PCA results across datasets). Sensitivity analysis helps assess how such uncertainties affect the final index, ensuring that the system is robust to minor variations.

1.3 Example Interpretation

Suppose the sensitivity analysis yields:

```
'sensitivity': {
    'Internet_Access': 0.02,
    'Mobile_Penetration': 0.015,
    'Internet_Banking': 0.005
}
```

This indicates that a 10% increase in the weight of "Internet_Access" changes the DAI scores by an average of 0.02 units, while "Internet_Banking" has a smaller impact (0.005 units). If the changes are small and consistent across parameters, the index is likely robust. If one parameter (e.g., "Internet_Access") causes a disproportionately large change, it may warrant re-evaluating its weight or the data quality.

1.4 Practical Implications

- **Policy Decisions**: If the DAI is used to allocate resources (e.g., improving internet access in villages), sensitivity analysis ensures that the rankings of villages are reliable and not drastically altered by small weight changes.

- **Iterative Refinement**: High sensitivity for a parameter may prompt further investigation, such as checking for data quality issues or consulting domain experts to adjust weights.
- **Scalability**: As new parameters (e.g., digital literacy) are added, sensitivity analysis helps assess their impact on the index, ensuring the system remains stable.

1.5 Conclusion

In summary, sensitivity analysis in the `DigitalAccessibilityIndex` class is a critical step to ensure the DAI is robust, reliable, and suitable for practical applications. It provides insights into the stability of the index and helps identify parameters that significantly influence the results, guiding both technical refinements and policy decisions.