In [36]:
```
# Lab 05– Classification Models &amp;amp; Ensemble Evaluation
# Learning Outcomes
# By the end of this lab, students will be able to:
# Train logistic regression, decision tree (using library and from scratch)
# Evaluate models using accuracy, ROC AUC, and confusion matrix.
# Interpret trade-offs between models.
# P – Project

# Preprocess Churn dataset (encoding, scaling).
# Train/test split.
# Fit:
# Logistic Regression
# Decision Tree
# Evaluate all models with metrics table &amp;amp; ROC curves.
# Save best model.
# Resources
# Sklearn Model Evaluation – https://scikitlearn. org/stable/modules/model_evaluation.html
# Confusion Matrix in Sklearn – https://scikitlearn.
# org/stable/modules/generated/sklearn.metrics.confusion_matrix.html
```

In [37]:
```
import pandas as pd
import numpy as np
from pathlib import Path

from sklearn.model_selection import train_test_split
from sklearn.preprocessing import OneHotEncoder, StandardScaler
from sklearn.compose import ColumnTransformer
from sklearn.pipeline import Pipeline
from sklearn.linear_model import LogisticRegression
from sklearn.tree import DecisionTreeClassifier, plot_tree
from sklearn.metrics import (
    accuracy_score,
    roc_auc_score,
    confusion_matrix,
    RocCurveDisplay,
    classification_report
)
from sklearn.utils.validation import check_is_fitted

import joblib
import matplotlib.pyplot as plt

pd.set_option('display.max_columns', None)
np.set_printoptions(suppress=True)
```

In [38]:
```
dataset_path = "LabAssig5_stuff/churn.csv"

df = pd.read_csv(dataset_path)
df = df.dropna(subset=["Churn"])

# Normalize to binary int
df["Churn"] = df["Churn"].astype(str).str.strip()
y = df["Churn"].map({
    True: 1, False: 0,
    "True": 1, "False": 0,
    "Yes": 1, "No": 0,
    "Y": 1, "N": 0,
    "1": 1, "0": 0
}).astype(int)

X = df.drop(columns=["Churn"])
print("Shape:", df.shape)
display(df.head(3))
```

```
Shape: (667, 20)
```

	State	Account length	Area code	International plan	Voice mail plan	Number vmail messages	Total day minutes	Total day calls	Total day charge	Total eve minutes	Total eve calls	Total eve charge	T n minu
0	LA	117	408	No	No	0	184.5	97	31.37	351.6	80	29.89	2
1	IN	65	415	No	No	0	129.1	137	21.95	228.5	83	19.42	2(
2	NY	161	415	No	No	0	332.9	67	56.59	317.8	97	27.01	1(

In [39]:
```
# Identify numeric and categorical columns
num_cols = X.select_dtypes(include=[np.number]).columns.tolist()
cat_cols = X.select_dtypes(exclude=[np.number]).columns.tolist()

# Handle all-NaN or empty
if len(num_cols) == 0 and len(cat_cols) == 0:
    raise ValueError("No usable feature columns found.")

num_transformer = StandardScaler()

try:
    cat_transformer = OneHotEncoder(handle_unknown="ignore", sparse_output=False)
except TypeError:
    cat_transformer = OneHotEncoder(handle_unknown="ignore", sparse=False)

preprocess = ColumnTransformer(
    transformers=[
        ("num", num_transformer, num_cols) if len(num_cols) else ("num", "drop", []),
        ("cat", cat_transformer, cat_cols) if len(cat_cols) else ("cat", "drop", []),
    ]
)

print(f"# numeric: {len(num_cols)}, # categorical: {len(cat_cols)}")
```

```
# numeric: 16, # categorical: 3
```

In [40]:
```
# Stratification condition
strata = y if y.nunique() > 1 else None

X_train, X_test, y_train, y_test = train_test_split(
    X, y,
    test_size=0.2,
    random_state=42,
    stratify=strata
)

print("Train shape:", X_train.shape, " Test shape:", X_test.shape)
print("Target balance (train):", y_train.mean().round(4))
print("Target balance (test):", y_test.mean().round(4))
```

```
Train shape: (533, 19)  Test shape: (134, 19)
Target balance (train): 0.1426
Target balance (test): 0.1418
```

In [41]:
```
log_reg = Pipeline([
    ("preprocess", preprocess),
    ("model", LogisticRegression(max_iter=2000, solver="lbfgs", n_jobs=None))
])

dtree = Pipeline([
    ("preprocess", preprocess),
    ("model", DecisionTreeClassifier(random_state=42))
])

# Fit models
log_reg.fit(X_train, y_train)
dtree.fit(X_train, y_train)

check_is_fitted(log_reg)
check_is_fitted(dtree)
```

In [42]:
```python
def evaluate_model(name, pipe, X_tr, y_tr, X_te, y_te, threshold=0.5):
    # Get probabilities for positive class
    if hasattr(pipe, "predict_proba"):
        y_tr_prob = pipe.predict_proba(X_tr)[:, 1]
        y_te_prob = pipe.predict_proba(X_te)[:, 1]
    else:

        if hasattr(pipe, "decision_function"):
            from sklearn.preprocessing import MinMaxScaler
            scaler = MinMaxScaler()
            y_tr_raw = pipe.decision_function(X_tr).reshape(-1, 1)
            y_te_raw = pipe.decision_function(X_te).reshape(-1, 1)
            y_tr_prob = scaler.fit_transform(y_tr_raw).ravel()
            y_te_prob = scaler.transform(y_te_raw).ravel()
        else:
            raise ValueError(f"Model {name} has neither predict_proba nor decision_function.")

    # Thresholding
    y_tr_pred = (y_tr_prob >= threshold).astype(int)
    y_te_pred = (y_te_prob >= threshold).astype(int)

    # Metrics
    acc_tr = accuracy_score(y_tr, y_tr_pred)
    acc_te = accuracy_score(y_te, y_te_pred)
    auc_tr = roc_auc_score(y_tr, y_tr_prob) if y_tr.nunique() > 1 else np.nan
    auc_te = roc_auc_score(y_te, y_te_prob) if y_te.nunique() > 1 else np.nan
    cm = confusion_matrix(y_te, y_te_pred, labels=[0, 1])

    # report
    clf_rep = classification_report(y_te, y_te_pred, labels=[0, 1], target_names=["No", "Yes"],

    return {
        "model": name,
        "accuracy_train": acc_tr,
        "accuracy_test": acc_te,
        "roc_auc_train": auc_tr,
        "roc_auc_test": auc_te,
        "confusion_matrix_test": cm,
        "classification_report_test": clf_rep,
        "threshold": threshold,
        "y_test_prob": y_te_prob
    }
```

In [43]:
```python
results = [
    evaluate_model("Logistic Regression", log_reg, X_train, y_train, X_test, y_test, threshold=0.
    evaluate_model("Decision Tree", dtree, X_train, y_train, X_test, y_test, threshold=0.5),
]

metrics_table = pd.DataFrame([{
    "Model": r["model"],
    "Accuracy (Train)": r["accuracy_train"],
    "Accuracy (Test)": r["accuracy_test"],
    "ROC AUC (Train)": r["roc_auc_train"],
    "ROC AUC (Test)": r["roc_auc_test"],
    "Threshold": r["threshold"],
} for r in results]).sort_values(
    by=["ROC AUC (Test)", "Accuracy (Test)"], ascending=[False, False]
).reset_index(drop=True)

display(metrics_table)

# confusion matrices and classification reports
for r in results:
    print("="*80)
    print(r["model"])
    print("Threshold:", r["threshold"])
    print("Confusion Matrix (Test) [rows: true 0,1; cols: pred 0,1]:")
    print(r["confusion_matrix_test"])
```

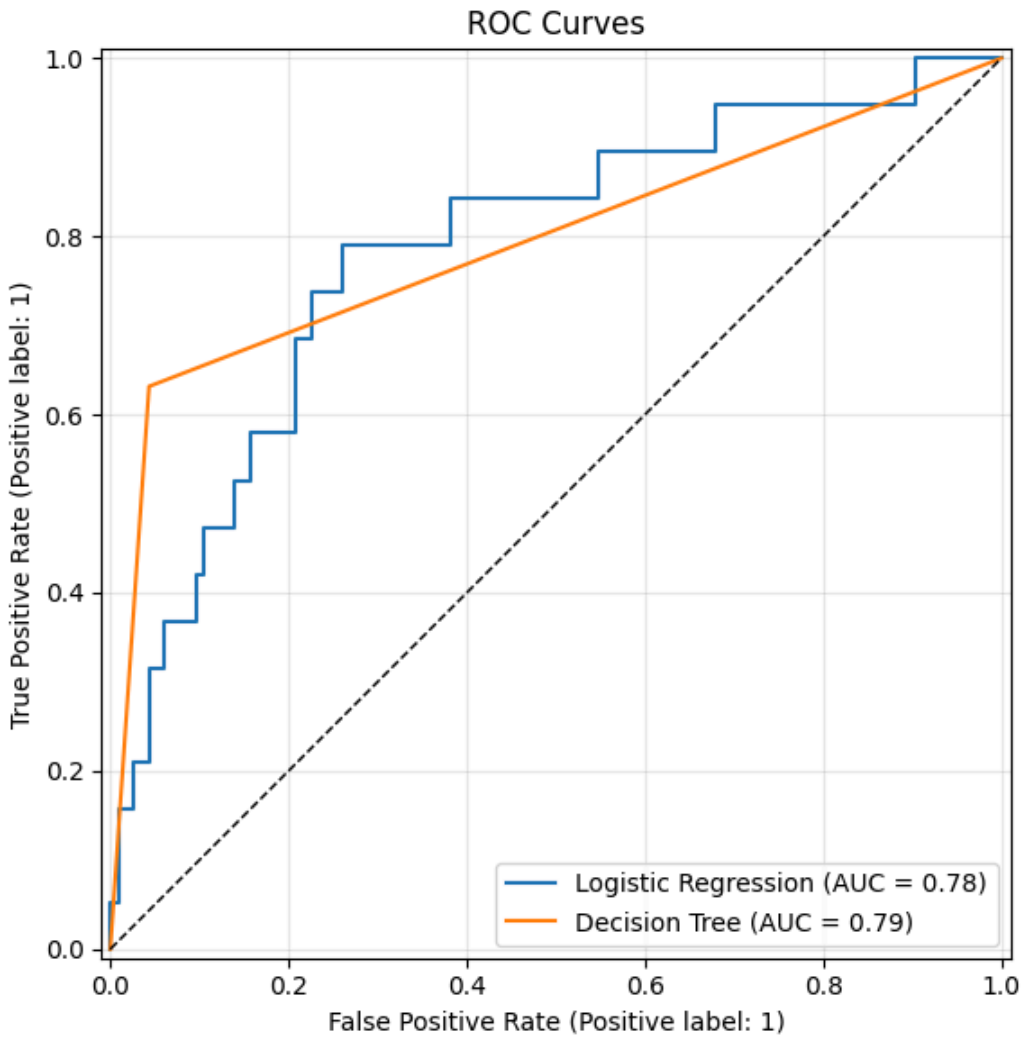
```
    print("\nClassification Report (Test):")
    print(r["classification_report_test"])
```

	Model	Accuracy (Train)	Accuracy (Test)	ROC AUC (Train)	ROC AUC (Test)	Threshold
0	Decision Tree	1.00000	0.910448	1.000000	0.794050	0.5
1	Logistic Regression	0.88743	0.858209	0.877721	0.783982	0.5

```
================================================================================
Logistic Regression
Threshold: 0.5
Confusion Matrix (Test) [rows: true 0,1; cols: pred 0,1]:
[[112   3]
 [ 16   3]]

Classification Report (Test):
              precision    recall  f1-score   support

          No       0.88      0.97      0.92       115
         Yes       0.50      0.16      0.24        19

    accuracy                           0.86       134
   macro avg       0.69      0.57      0.58       134
weighted avg       0.82      0.86      0.83       134

================================================================================
Decision Tree
Threshold: 0.5
Confusion Matrix (Test) [rows: true 0,1; cols: pred 0,1]:
[[110   5]
 [  7  12]]

Classification Report (Test):
              precision    recall  f1-score   support

          No       0.94      0.96      0.95       115
         Yes       0.71      0.63      0.67        19

    accuracy                           0.91       134
   macro avg       0.82      0.79      0.81       134
weighted avg       0.91      0.91      0.91       134
```

In [44]:

```
plt.figure(figsize=(7, 6))
ax = plt.gca()
try:
    RocCurveDisplay.from_estimator(log_reg, X_test, y_test, name="Logistic Regression", ax=ax)
    RocCurveDisplay.from_estimator(dtree, X_test, y_test, name="Decision Tree", ax=ax)
    ax.plot([0, 1], [0, 1], "k--", linewidth=1)
    plt.title("ROC Curves")
    plt.grid(True, alpha=0.3)
    plt.tight_layout()
    plt.show()
except Exception as e:
    print("ROC plot skipped:", e)
```

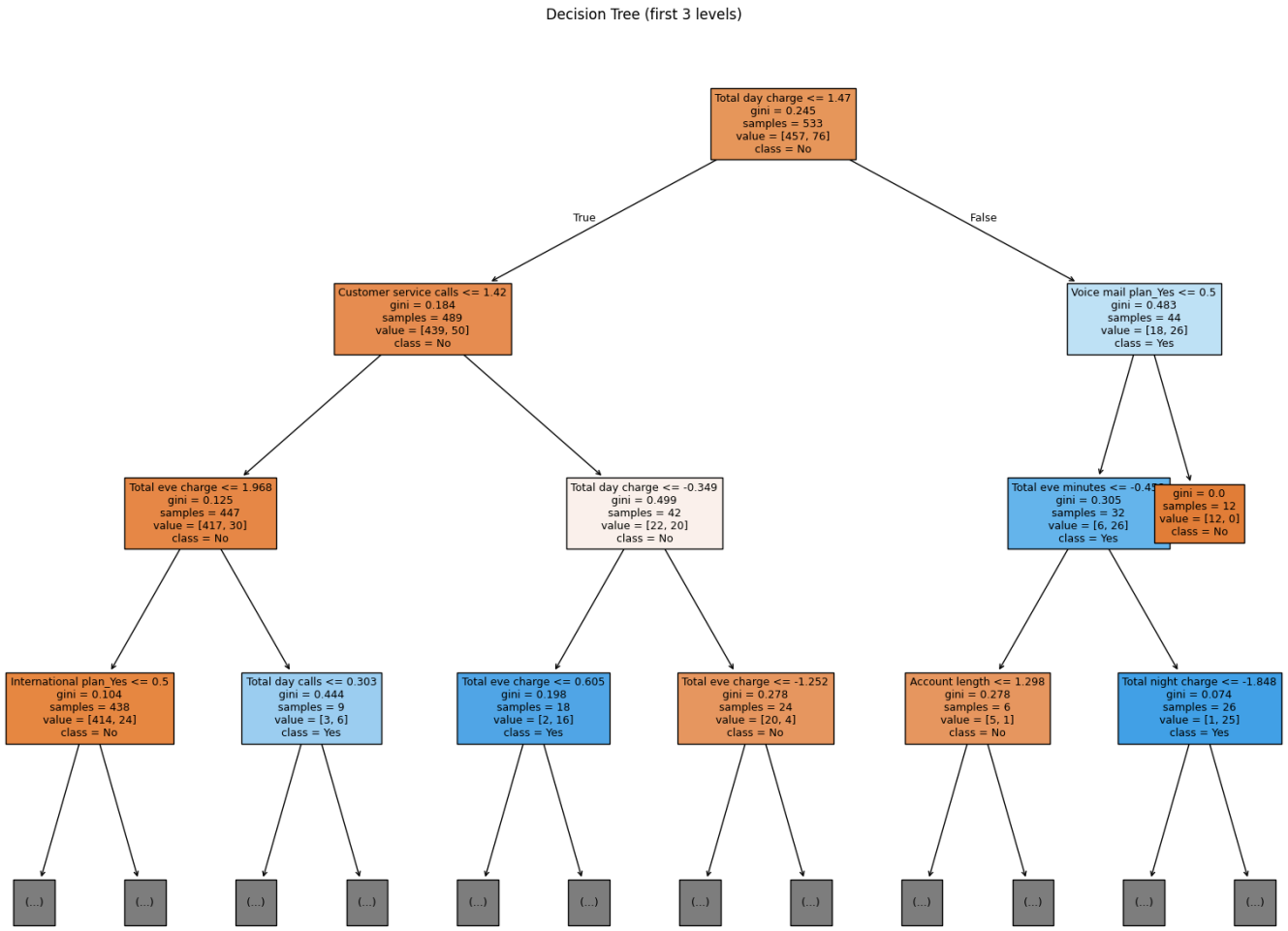


In [45]:
```python
# ROC AUC else accuracy
if metrics_table["ROC AUC (Test)"].notna().any():
    best_col = "ROC AUC (Test)"
else:
    best_col = "Accuracy (Test)"

best_idx = metrics_table[best_col].values.argmax()
best_name = metrics_table.iloc[best_idx]["Model"]
best_model = {"Logistic Regression": log_reg, "Decision Tree": dtree}[best_name]

print("Best model:", best_name, "| criterion:", best_col)

Path("models").mkdir(parents=True, exist_ok=True)
model_path = Path("models") / f"best_model_{best_name.replace(' ', '_').lower()}.joblib"
joblib.dump(best_model, model_path)
print("Saved to:", model_path)
```

```
Best model: Decision Tree | criterion: ROC AUC (Test)
Saved to: models/best_model_decision_tree.joblib
```

In [46]:
```python
if "Decision Tree" == best_name:
    # Extract preprocess and feature
    fitted_pre = best_model.named_steps["preprocess"]
    # Extract OHE object safely
    try:
        ohe = fitted_pre.named_transformers_["cat"]
    except Exception:
        ohe = None

    if ohe is not None and len(cat_cols) > 0:
        try:
            cat_feature_names = ohe.get_feature_names_out(cat_cols).tolist()
        except Exception:
            cat_feature_names = ohe.get_feature_names(cat_cols)
            if not isinstance(cat_feature_names, list):
```

```
                cat_feature_names = list(cat_feature_names)
    else:
        cat_feature_names = []

    feature_names = num_cols + cat_feature_names
    clf = best_model.named_steps["model"]

    plt.figure(figsize=(16, 12))
    plot_tree(
        clf,
        feature_names=feature_names if len(feature_names) else None,
        class_names=["No", "Yes"],
        filled=True,
        max_depth=3,
        fontsize=9
    )
    plt.title("Decision Tree (first 3 levels)")
    plt.tight_layout()
    plt.show()
```



In [47]:
```
threshold_rows = []
if "log_reg" in globals():

    check_is_fitted(log_reg)
    probas = log_reg.predict_proba(X_test)[:, 1]
    thresholds = np.linspace(0.1, 0.9, 9)

    for t in thresholds:
        y_pred = (probas >= t).astype(int)
        acc = accuracy_score(y_test, y_pred)
        auc = roc_auc_score(y_test, probas) if y_test.nunique() > 1 else np.nan
        tn, fp, fn, tp = confusion_matrix(y_test, y_pred, labels=[0, 1]).ravel()
        tpr = tp / (tp + fn) if (tp + fn) > 0 else 0.0
        fpr = fp / (fp + tn) if (fp + tn) > 0 else 0.0
        threshold_rows.append({"threshold": float(t), "accuracy": float(acc), "roc_auc": float(au
```

```
threshold_df = pd.DataFrame(threshold_rows)
display(threshold_df)
```

	threshold	accuracy	roc_auc	tpr	fpr
0	0.1	0.746269	0.783982	0.736842	0.252174
1	0.2	0.798507	0.783982	0.526316	0.156522
2	0.3	0.835821	0.783982	0.368421	0.086957
3	0.4	0.865672	0.783982	0.315789	0.043478
4	0.5	0.858209	0.783982	0.157895	0.026087
5	0.6	0.873134	0.783982	0.157895	0.008696
6	0.7	0.865672	0.783982	0.052632	0.000000
7	0.8	0.865672	0.783982	0.052632	0.000000
8	0.9	0.858209	0.783982	0.000000	0.000000

In [48]:
```
Path("LabAssig5_stuff").mkdir(parents=True, exist_ok=True)
metrics_out = Path("LabAssig5_stuff") / "model_metrics.csv"
metrics_table.to_csv(metrics_out, index=False)
print(str(metrics_out))
```

```
LabAssig5_stuff/model_metrics.csv
```